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FURTHER INVESTIGATIONS ON BUSH-SICKNESS AT GLENHOPE, NELSON, NEW ZEALAND

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WITH PLATE I

Introduction.—In a previous publication [1] attention was drawn to the strikingly beneficial results that were obtained by the use of a soil drench in the prevention of bush-sickness at Glenhope, Nelson. The work reported there was continued for a longer period, with the result that the sheep which received drench-treatments of ferric ammonium citrate or of Parapara limonite, or which remained without treatment, went off in health quickly in the following spring so that by midsummer not one of the nineteen animals originally in these groups remained alive.[1] On the other hand, the animals receiving the Nelson-soil drench continued in perfect condition and by April 14 of the second season showed an average live-weight of 141 lb. These sheep were held on the same bush-sick pasture until the following October (1934), having been two years on the soil drench. All the animals were perfectly healthy and in very good condition.

In view of the results obtained by Filmer and Underwood [2] in Western Australia with dilute-acid extracts of limonite, even in the iron-free condition, for the treatment of a disease showing some similarities to bush-sickness, it was thought desirable to see whether the beneficial constituents of Nelson soil were readily soluble in dilute hydrochloric acid. A drench was accordingly prepared and used during the 1934–5 season.

Experimental

Five groups of six hoggets each, introduced from healthy country, were grazed on the bush-sick pasture at Glenhope. The groups represented the following treatments:

1. Control.
2. Nelson soil as used in previous seasons.
3. Acid extract of Nelson soil.
4. Extracted Nelson soil.
5. Wakatu soil.

This last treatment was introduced in order to test another Nelson-soil type which, so far as is known, is healthy to stock. Drenching twice weekly with equivalent amounts of soil was carried out, commencing on October 12, 1934.

The extract from the Nelson soil was obtained by heating one part of soil with 10 parts of N/8 hydrochloric acid; after filtering, the soil was washed a few times with water and then dried for use as one of the above treatments (extracted soil). The liquid extract was evaporated to a volume convenient for drenching purposes; a volume of liquid corresponding to the same amount of soil employed in the other groups was used. It must

[1] Unpublished results.

be emphasized that this process of extraction was not very rigorous, so that all of the beneficial constituents may not have been removed from the soil.

The animals were weighed and arranged in groups on October 12, 1934, after being on the bush-sick pasture for a week or two to settle down to their new surroundings. The first drench was administered to the respective groups on the same date.

Results

In Table 1, and in the accompanying graph (Fig. 1), are shown the average live-weights of the sheep in the various groups throughout the

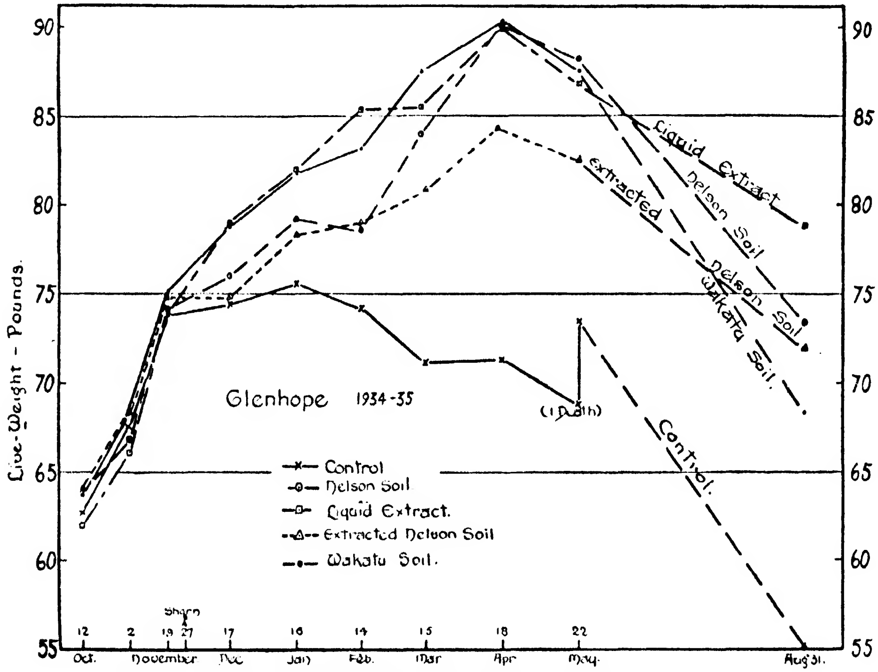

Fig. 1. Average live-weights of sheep in groups at Glenhope.

period of the experiments. There is a long period from May 22, 1935, to August 31, 1935, during which weight records were not taken; field notes covering the condition of the sheep for this intervening period are, however, available.

The records indicate that all the groups receiving drenches increased steadily in weight until the middle of April; but of these groups the extracted-soil group was the least satisfactory. All the animals were, however, healthy. The curve for the control group reached its maximum in the middle of January with an average live-weight at this period of 75·6 lb., whereas the acid-extract group, for example, at this time had an average weight of 82·0 lb. By the middle of January at least one sheep in the control was showing signs of bush-sickness. As the season progressed

TABLE 1. *Average Live-weight in Pounds of Sheep receiving Drench-treatment, Glenhope 1934–5*

Treatment	*Oct. 12, 1934*	*Nov. 2, 1934*	*Nov. 19, 1934*	*Dec. 17, 1934*	*Jan. 16, 1935*	*Feb. 14, 1935*	*Mar. 15, 1935*	*Apr. 18, 1935*	*May 22, 1935*	*Aug. 31, 1935*
Control	62·7	67·6	73·8	74·4	75·6	74·2	71·2	71·4	68·8	55·2
Nelson soil	63·9	66·8	74·2	76·0	79·2	78·6	84·0	90·2	88·2	73·4
Acid extract of Nelson soil	62·0	66·2	74·0	79·0	82·0	85·4	85·5	90·0	86·8	78·8
Extracted Nelson soil	63·9	68·3	74·8	74·8	78·3	79·0	80·8	84·3	82·5	72·0
Wakatu soil	63·7	68·3	75·2	78·8	81·8	83·2	87·5	90·3	87·5	68·4

NOTE: Sheep were shorn on Nov. 27, 1934.

more of the animals of the control group became affected with bush-sickness, whereas until the end of June the animals of the other groups remained healthy. The loss in weight shown after April is due mainly to the onset of cold weather and cessation of active pasture-growth. In the late autumn and winter the sheep in the control group became badly affected with bush-sickness; this is shown plainly in the graph by the rapid loss in weight. The break in the curve of the control group at May 22 is due to a recalculation of the live-weight of the group following the death of one animal about June 1.

All of the other groups show considerable losses in weight, the losses being least in the cases of the Nelson-soil and the acid-extract groups; of these two the acid extract was the better group. On August 31, 1935, all the animals in these two groups were healthy and in very fair condition considering the inclement weather to which they had been exposed. In the extracted-soil and Wakatu-soil groups, however, cases of bush-sickness appeared early in July, and by August 31 several animals of each group were badly affected, whilst others showed symptoms of approaching sickness.

Discussion

The live-weight data presented above show that very definite differences occur in the ability of the several drench-treatments to prevent the onset of bush-sickness. Whereas the Nelson-soil and the acid extract have maintained the animals in good health, the other two soil drenches (extracted soil and Wakatu soil) have not been able to keep the animals healthy. It is important to note that the last two groups appeared to give satisfactory results until the late autumn, and that bush-sickness appeared in the winter. The explanation of this may be that the quantity of the active constituent, or constituents, present in these soils, although beneficial, was not sufficient to maintain the sheep in health over an extended period in which, owing to cold weather and shortage of feed, the sheep were subjected to extra strain.

In the case of the Wakatu soil it might well be asked: why do sheep remain healthy when grazed on pastures established on the soil type whilst in drench form the same soil has proved only partly successful at Glenhope in preventing the incidence of bush-sickness? This may be

explained by the fact that sheep grazing Wakatu pastures actually ingest much more soil than was supplied to the sheep at Glenhope in drench form. The larger quantity of soil, combined with a probable higher intake by Wakatu pastures of the active constituent, or constituents, would thus account for the healthy conditions of sheep on Wakatu farms.

The photographs, taken on September 4, 1935, show that the sheep receiving Wakatu soil (Fig. 2 (*b*), Pl. 1) are by no means so good as the sheep receiving the acid extract (Fig. 2 (*a*), Pl. 1), they having gained only an average of 4 lb. over their weight of October 12, as against an average gain of 17 lb. shown by the sheep receiving the acid extract. The control group (Fig. 2 (*c*), Pl. 1), are in very poor condition, and are 5 lb. per head below their weight when the experiment began.

The Nelson-soil and acid-extract groups remain for consideration. It will have been noticed that at the end of the season the Nelson-soil group is not much heavier than the extracted-soil group, and that this group was only 9 lb. heavier per head than at the beginning of the season. The average weight of the Nelson-soil group was reduced by the presence of a thin, constitutionally weaker animal, which, however, does not show any signs of bush-sickness. All the animals in the above two groups are quite healthy and carry good bright wool, in contrast with the harsh, dry, and lustreless wool of the control group.

The results of this season's work indicate definitely that the acid extract of Nelson soil has given very good results, in fact, the best result of all the treatments. This suggests that the beneficial properties of Nelson soil are connected with a constituent, or constituents, soluble in dilute hydrochloric acid. This suggestion is confirmed by the inability of the extracted soil to maintain sheep in health over an extended period.

Analysis of the acid extract shows that the sheep would receive a supplement of 50 mgm. of iron (Fe) per week by this drench-treatment. A supplement of only 7 mgm. of iron per day in the diet of the sheep does not appear to explain the beneficial results that have been obtained by the use of this acid extract of Nelson soil. A consideration of the iron-intake of sheep grazing Glenhope pastures shows that, on a basis of 0·006 per cent. of iron (Fe) in the pastures, the sheep would obtain not less than 60 mgm. of iron (Fe) per day, without including additional iron obtained by ingesting Glenhope soil. A supplement of 7 mgm. of iron per day is such a small addition to the normal iron-intake of Glenhope sheep that it seems highly improbable that the beneficial results obtained by administering the acid soil-extract are due solely or mainly to this increment in the iron supply of the sheep.

The results secured with the Wakatu soil show clearly that apparently healthy sheep soils, when used in drench form on Glenhope sheep, vary in their effectiveness in combating bush-sickness. The most probable explanation of the beneficial properties of the acid extract of Nelson soil is that some constituent, or constituents, other than iron, are mainly responsible for the good results which have been obtained. The Wakatu soil does not appear to possess a high supply of the beneficial constituent, or constituents.

Fig. 2 (*a*). Sheep receiving Acid Extract of Nelson soil. Sept. 4, 1935

Fig. 2 (*b*). Sheep receiving Wakatu soil. Sept. 4, 1935

Fig. 2 (*c*). Control group. Sept. 4, 1935

Examination of the acid extract of Nelson soil shows the presence of a number of metallic elements, for example, cobalt, nickel, copper, &c. In view of the amazing results obtained by Australian workers in connexion with 'coast disease' [3] and with enzootic marasmus in Western Australia [4] by the use of minute quantities of cobalt, it does appear probable that one or more of these trace elements may be concerned in the beneficial effects noted in the case of Glenhope sheep treated with an acid extract of Nelson soil.

This possibility is being further explored during the coming season. An iron-free extract of Nelson soil will be tested on one group of sheep, and other tests will be made of some of the trace metals which have already been identified in the acid extract of Nelson soil.

Summary

1. The good results obtained with a drench of Nelson soil for sheep on a bush-sick pasture have been confirmed.

2. An acid extract of Nelson soil used in the liquid condition has given very good results in the prevention of bush-sickness.

3. The residual soil after extraction with acid was not found to prevent the onset of bush-sickness.

4. A second soil from the Nelson district was not found satisfactory in preventing the onset of bush-sickness.

5. The iron-content of the acid extract of Nelson soil did not appear to be the only factor in the control of bush-sickness at Glenhope. Other elements present in small quantities are probably the beneficial constituents in Nelson soil and in the liquid extract of Nelson soil.

Acknowledgements

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THE CROPPING QUALITIES OF CERTAIN TROPICAL FODDER GRASSES

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WITH PLATE 2

The Experiment

IN two earlier publications [1, 2] the writer has emphasized the need and importance of scientific research on tropical fodder crops. The available information on this aspect of tropical agriculture is particularly meagre, and in consequence the following account of a small field trial of six varieties of fodder grass grown in Trinidad has been prepared, as it does add a little to our knowledge of a subject that has been rather neglected in the past. The experiment consisted essentially of observation plots on which six fodder grasses were planted and subjected to various cultural treatments. The total area involved was small, and the layout did not permit a valid statistical interpretation of the yield data. In place of this, accurate field notes were kept week by week recording the differential behaviour of the grasses under the various treatment series. The results, within the limits of a single experiment, were both striking and conclusive, and are summarized in the following pages.

The varieties included were:

Elephant Grass (*Pennisetum purpureum*)
Guatemala Grass (*Tripsacum laxum*)
Guinea Grass (*Panicum maximum*)
Para Grass (*Panicum barbinode*)
Uba Cane (*Saccharum sinense*, var. *Uba*)
Coimbatore Cane (*Saccharum sinense*, var. *Co. 213*).

Accurate botanical descriptions of these species may be found in the references cited [3–6]. It will suffice here to state that they are all well-known perennial grasses which thrive under the climatic and soil conditions prevailing in the humid tropics, where they are being cultivated on an increasing scale as fodder crops. They are generally utilized on the soiling system, but they may also occur naturally in the herbage of waste and pasture lands, where they may be grazed. Planting of the experimental area took place in May 1933, propagation being obtained from root-division of old stools. All species were given three months in which to get established and were first sown on August 9, when the experimental period commenced. Records were taken over the ensuing twelve months.

During the establishment-period two inter-cultivations with the horse-hoe were carried out to keep down weeds, and the blanks were twice supplied. At the beginning of the experiment proper in August, the stand on all plots was approximately 100 per cent. Before planting, farmyard manure at the rate of 15 tons per acre was broadcast over the whole area and ploughed in. During the experiment light dressings of a complete organic fertilizer were applied at three-monthly intervals.

This compound manure, of which blood-meal was the chief ingredient, contained approximately N 11, P_2O_5 2, and K_2O 10 per cent.; it was broadcast between the rows at the rate of 2 cwt. per acre, and lightly hoed into the surface-soil. The soil on the experimental site has been described [7] as a sandy loam of medium-low nutrient status, and periodic applications of manure are essential in order to maintain fertility and counteract the effects of leaching and continuous cropping.

The area under each fodder grass was divided into small sub-plots on which the following treatments were located in all combinations:

Treatment	*Descriptions*
Spacing	$2\times1\frac{1}{2}$ ft. and 3×2 ft.
Cutting-rotations . . .	A. Cut every 45 days or 8 times per year
	B. ,, 90 ,, 4 ,, ,,
	C. ,, 120 ,, 3 ,, ,,
	D. ,, 180 ,, 2 ,, ,,
Height of cutting . . .	Shaved, i.e. cut at ground-level
	Normal, ,, ,, 4–6 in. above ground-level
	High, ,, ,, 9–12 in. ,, ,,

Propagation.—Varietal differences as regards number of successes and growth-increment were quickly apparent. The Elephant Grass sprouted the best, the majority of the sets taking root and giving a good leaf-growth in a comparatively short period. The Uba Cane and the Guatemala Grasses were decidedly the poorest, needed the greatest number of supplies, and showed the lowest productivity. The other three fodders —the Co. 213 Cane, Para Grass, and Guinea Grass—were not quite up to the standard of the Elephant Grass. The Coimbatore Cane was superior to the Uba. The following yields of green herbage per 1/40th acre plot, as recorded at the preliminary mowing, reflect the comparative growth-rate of the six fodders during the establishment-period:

Elephant Grass . . .	617 lb.	Co. 213 Cane . . .	351 lb.
Guinea Grass . . .	509 ,,	Guatemala Grass . .	121 ,,
Para Grass	473 ,,	Uba Cane	78 ,,

In the original planting, single-tiller root-sections were used throughout. For the supplies larger sets consisting of 2–3 tillers-cum-roots were tried and gave a much greater percentage of successes, and also improved early productivity. These supplies were put in some three weeks after planting, yet, at the first harvest, it was impossible to distinguish any difference in size between them and the older stools. The later sets, which were planted after the rainy season had effectively set in, were undoubtedly favoured. This is not surprising, as many tropical grasses, e.g. Para and Elephant Grass, are naturally adapted to thrive best under very wet semi-swamp conditions.

Regeneration.—It has already been noted [2] that the ratoon-crop can be produced in two ways, by terminal or bud-development. The interaction between the cutting technique and the regeneration habit of the plant is looked upon as particularly important in view of its influence on yield, on plant-survival, and even on the nutritive quality of the herbage. In the tropics there is a much greater tendency for plants to shoot than

in temperate regions, and under certain conditions this might give rise to relatively poor tillering. The explanation is, presumably, that the rapidly developing main axis utilizes the majority of the nutritive elements absorbed by the roots, and, in addition, may even carry up with it many of the potential buds that might otherwise have given rise to new tillers.

As elongation of the original axis can occur only when the terminal buds are left on the stool at harvest, there are two factors which largely determine the method of regeneration that will be adopted by the plant, (*a*) the height at which the bud is located at harvest, and (*b*) the height at which mowing occurs. Now the former factor depends on the length of the main axis, and this in turn on its age, or in other words, on the number of days from the previous harvest. In the 'frequently-cut' series, the produce never grows beyond the leafy stage, the culms are short and the growing tip of each shoot is relatively close to the ground. Under these circumstances the terminal bud is not likely to be reaped, and terminal sprouting generally results. On the other hand, in the long cutting-rotations the culms are well developed, mowing almost certainly occurs below the level of the growing point, and bud-sprouting must follow. These features were most marked in the case of Guinea and Guatemala Grass and least evident in the Para Grass, whose tangled habit of growth and faculty of rooting wherever the nodes come in contact with the ground made it impossible to determine accurately how the ratoons were produced. In the case of the two canes in Series D—the 6-month rotation—the presence of a fair percentage of terminal sprouts was at first rather surprising. They were generally located round the periphery of each stool, and were traced to young immature tillers which had been harvested along with the more mature canes on the rest of the stool. A combination of both types of sprouting is desirable to ensure the production of large virile stools, and on the average this duplicate regeneration does occur when a 3–4-month rotation is adopted.

It should now be readily understood why the height of mowing is of such importance in determining regeneration-habit. The shaving of the stools to ground-level must cause in every stool, not excluding those of Series A, bud-sprouting only, whereas cutting at one foot high tends to encourage terminal development, as then, except in the case of semi-mature herbage, removal of the terminal buds will rarely occur. Furthermore, as terminal development is associated with rapid ratooning, quicker growth might be expected on the 'high-cut' plots than on those cut low or shaved. This was demonstrated conclusively in the experiment. Even at the succeeding harvest there was a definite height-gradation in the produce of any one cutting series, according to the level at which the stools had been reaped. Height-measurements were taken before every harvest of 10 stools selected at random from each treatment. The height recorded for each stool represented the average of the five longest tillers. The mean values for the season are recorded in Table 1.

Owing to the growth-peculiarities of the Para and Elephant Grass it was not possible to obtain comparable data for these two fodders. The same marked stepped effect in the height of the produce from the 'high-

TABLE I. *The Mean Height in Feet of the Herbage in each Treatment*

	Co. 213			*Uba Cane*			*Guinea Grass*			*Guatemala Grass*		
Series	*High cut* (H)	*Medium cut* (M)	*Shaved* (S)	H	M	S	H	M	S	H	M	S
A	4·54	3·77	2·72	4·32	3·64	1·71	3·75	2·37	1·83	3·55	3·01	2·05
B	6·60	5·66	4·50	6·30	5·58	4·34	4·20	4·04	3·64	4·70	4·16	3·44
C	9·75	8·60	7·75	9·25	8·30	7·75	6·10	5·75	5·25	6·50	5·30	5·00
D	9·75	9·10	8·60	9·10	8·50	7·75	6·00	5·25	4·60	8·00	7·10	6·20
Means	*7·66*	*6·78*	*5·89*	*7·24*	*6·50*	*5·39*	*5·01*	*4·35*	*3·83*	*5·69*	*4·89*	*4·17*
Means expressed as a percentage of the 'high-cut' values	100	88	77	100	90	74	100	87	76	100	86	73

cut' to the shaved plots was nevertheless present. This difference in level at harvest was too large to be explained by the initial few inches difference in the stools as a result of the cutting technique adopted, and it must be assumed that high cutting up to one foot leads to a ratoon-crop that will be ready for harvest relatively quickly. That this quicker maturing does actually occur is further attested by the fact that the flowering heads of the Guinea Grass always made their appearance first of all in the plots that had been mown high, and were rarely found on those that had been shaved. By altering the height of cutting in accordance with the number of days between harvests and the particular variety of grass, it is therefore possible to predetermine the system of regeneration that will be adopted by the ratoon-crop and approach the ideal in which rapid sprouting is coupled with multiple tillering. Other factors, in particular soil type and quantity of available nutrient, will also influence results in any particular locality. From the practical aspect it is possible that, in the final selection of method, high-cutting up to one foot might be slightly favoured, as this system avoids the severing of the hard fibrous bases of the culms and is easier on the labourer. It may slightly decrease the total weight of the cut fodder, but this should be more than compensated by the increase in nutritive quality of the produce as a result of the more leafy character of the herbage removed.

Stool survival.—As a test of the effects of the various treatments on the general vigour of the plant, the number of stools surviving on each subplot after every harvest was recorded. There did not appear to be any distinct seasonal trend in the stool mortality, and the final count taken in August, 1934, has been used as an index of the response of the plant to any particular treatment (Table 2).

Although an analysis of variance has been carried out on these figures, it is fully realized that the layout and the data are not such as to provide conclusive evidence regarding differences in mortality between the various treatments. The following results, although based on significant differences between treatment totals, are therefore tentative findings requiring further proof. The wider spacing has reduced the stool mortality. The survival percentage is highest in the Guinea Grass and lowest in the Uba Cane. The height of cutting and the rotation adopted have

TABLE 2. *Final Stool Population per Plot on August 20, 1934*

(based on a possible maximum of 24)

		Wide Spacing				Close Spacing				
		Co. 213	*Uba Cane*	*Guinea Grass*	*Guatemala Grass*	*Co. 213*	*Uba Cane*	*Guinea Grass*	*Guatemala Grass*	*Totals*
Series A	High-cut	23	24	24	24	24	24	24	24	191
	Normal	23	19	24	21	24	24	24	20	179
	Shaved	21	3	24	13	20	10	16	4	111
Series B	High-cut	23	24	24	24	23	24	24	24	190
	Normal	24	23	24	23	23	21	24	22	184
	Shaved	21	19	24	19	22	14	19	17	155
Series C	High-cut	24	24	24	23	19	22	24	24	184
	Normal	23	24	24	24	24	18	23	24	184
	Shaved	24	19	24	24	21	16	19	16	163
Series D	High-cut	24	24	24	24	22	22	23	24	187
	Normal	24	24	24	24	24	22	22	24	188
	Shaved	19	19	24	24	19	16	20	19	160
Totals		273	246	288	267	265	233	262	242	2,076
		1,074				1,002				

Variety Totals

Co. 213	538	Guinea Grass . .	550
Uba	479	Guatemala Grass . .	509

had a marked difference on the percentage survival. Differences greater than 22·0 between the totals given in the final column are statistically significant. This proves that shaving combined with frequent cutting produces the maximum mortality in the stools. Furthermore, shaving for each of the rotations separately has caused a definite lowering in the percentage survival. The explanation lies in the nature of the stool developed under the frequent-cutting rotation, as in Series A; it is definitely inferior in size, in number of tillers, and in root-development to those of the longer rotations [2]. This general effect was accentuated in the case of the shaved stools, which were markedly smaller than the adjacent high-cut stools of the same series. These conclusions are based on records obtained from four varieties of tropical fodder, and illustrate a general rule which has been shown to apply also to pastures in England [8, 9]. Cutting too frequently or mowing too closely impairs the general vigour of the plant, and results in a small underdeveloped stool with a poor root-system.

Hardiness.—In selecting a perennial fodder, it is not only the potential yield of nutriment per acre that must be considered, but also the ability of the crop to smother weed-growth. The varieties under test showed considerable differences in this direction. The Para and Guatemala Grasses were undoubtedly the best, and effectively smothered all extraneous vegetation. The Guinea Grass and Co. 213 Cane were both good. The Uba Cane and Elephant Grass permitted much the heaviest growth of weeds. As in earlier experiments [2], the occurrence of weeds in all the varieties was greatest in plots of Series A and least in those of Series D, where a long cutting-rotation was used. It was evident too that plots which were shaved were more prone to weed-infestation than those in which the stools were cut somewhat higher. This is to be expected, as

shaving results in slow ratooning, and ultimately in a certain mortality in the stools. The closer spacing, $2 \times 1\frac{1}{2}$ ft., tended to decrease the weed-population, particularly with the less vigorous fodders. The difference between the weeds on the two spacings was not considered sufficiently great to warrant the extra expense involved in close-planting: $3 \times 1\frac{1}{2}$ ft., or 3×2 ft., appears to be a satisfactory planting-distance for the average tropical fodder grass cropped on any reasonable cutting-rotation.

The only serious pest recorded was the *Helminthosporium* fungus on the Elephant Grass, as already noted [1, 2]. Under normal conditions Elephant Grass has all the characters essential to a good perennial fodder crop, including aggressiveness, persistence, high productivity and nutritive quality, and it has recently been introduced to several new areas with marked success. Except for its susceptibility to this particular fungus, Elephant Grass has therefore many excellent qualities, and an attempt is being made to produce a resistant strain.

Flowering in a perennial fodder grass is a feature that is not generally desirable, as it is usually accompanied by a loss in herbage-productivity and in nutritive quality. Two of the grasses showed a decided tendency to run into flower, namely, Guinea Grass and Para Grass. In Series B, C, and D, ranging from 3 to 6 months between cuts, flowers had always made their appearance before reaping occurred. At some seasons of the year, in Series D a second flush had time to develop before harvest became due. Even in Series A, with only $6\frac{1}{2}$ weeks between ratoons, some of the stools produced flower-heads. The fact that the inflorescences always appeared first in the high-cut stools has already been commented upon. Of the two flowering varieties, the undesirable change in growth-habit is particularly marked with Guinea Grass, whose inflorescence-panicle is borne on a long fibrous stalk, and whose foliage turns yellowish and apparently suffers a loss in nutritive quality. Flowering in the Para Grass is probably just as frequent, but it is not accompanied by any marked alteration in the vegetative growth, and the leaves and stems remain green and succulent. This susceptibility of the Guinea Grass to seed-production makes it definitely inferior to the other varieties as a fodder crop for Trinidad. It is grown by some farmers to provide roughage for horses, for whom a dry type of fodder is preferable.

The exceptionally severe dry spell of 1934 provided an excellent test of the respective capacities of the grasses to withstand drought. From January to August, 1934, the total rainfall amounted to 9·55 in., representing only 28 per cent. of the normal. The herbage-yields in consequence were reduced to about 25 per cent. of that of the wet season. The percentage mortality due to drought alone was apparently nil, so that it can be stated that all the grasses are hardy enough to withstand successfully dry-weather conditions, which, for Trinidad, were abnormally prolonged. The varieties showed considerable differences in their reactions to the dry season. The two canes suffered least and continued to yield a reasonable bulk of green fodder throughout the dry months. The Guatemala and Guinea Grasses turned very dry and yellow, and the leaves tended to roll up longitudinally into narrow spills. The Elephant Grass practically stopped growth as a result of combined fungal infection

and drought. The Para Grass altered its habit of growth and limited its development to the production of long prostrate runners, and as a result the yield of edible fodder was negligible.

Composition.—In order to provide material for chemical analysis, representative samples of the produce from the first harvest of each of the main treatment series were collected. Five stools were selected at random from each plot harvested, and sampled as described in [2]. The following figures, showing the nitrogen percentages from the duplicate samples of Series A, were recorded to ascertain whether or not the sampling technique was sufficiently accurate to give produce uniform in character and truly representative of the nutritional value of the series from which it had been obtained.

Series A. Harvested

Percentage Nitrogen in Dry Matter

	Elephant Grass	*Uba Cane*	*Guatemala Grass*	*Guinea Grass*	*Co. 213 Cane*	*Para Grass*
1st Sample	1·29	1·12	1·07	1·26	1·08	1·41
2nd Sample	1·28	1·11	1·05	1·14	1·04	1·49
Means .	*1·285*	*1·115*	*1·060*	*1·200*	*1·060*	*1·450*

Analysis of variance of these nitrogen percentages demonstrates that the variation within samples is negligible in comparison with that between samples, and that the maximum difference between any pair of duplicate readings is statistically non-significant. A difference between varietal means greater than 0·11 is significant, proving that there is a considerable and real difference in the nitrogen-content of the six varieties. Para Grass is decidedly the best, but Uba, Co. 213 Cane, and Guatemala Grass are relatively low in nitrogen. In general, a difference exceeding some 9 per cent. of the mean values quoted may be taken as real on a probability of 0·05. The results of the chemical analysis are summarized in Table 3.

TABLE 3. *Dry-Matter and Protein-Percentages for the Different Varieties and Cutting-Rotations*

Fodder	*Percentage Dry Matter*				*Variety Mean*	*Percentage Crude Protein in Dry Matter*				*Variety Mean*
	A	*B*	*C*	*D*		*A*	*B*	*C*	*D*	
Elephant Grass .	13·38	21·53	24·35	23·25	*20·65*	9·61	5·93	6·06	4·87	*6·62*
Guatemala Grass .	16·40	16·45	16·95	22·82	*18·15*	8·12	5·74	3·88	3·31	*5·26*
Uba Cane . .	14·15	16·64	18·46	24·75	*18·50*	7·56	4·25	4·37	2·25	*4·61*
Co. 213 . . .	17·69	15·46	19·87	26·45	*19·87*	7·44	5·24	4·18	2·75	*4·90*
Guinea Grass . .	16·16	19·37	24·33	31·85	*22·93*	8·37	5·43	5·87	3·75	*5·85*
Para Grass . .	18·05	17·42	22·08	17·15	*18·68*	11·08	6·87	6·65	4·00	*7·15*
Rotation mean	*15·97*	*17·81*	*21·01*	*24·38*		*8·70*	*5·58*	*5·17*	*3·49*	

These figures indicate, as is to be expected, a marked progressive increase in dry-matter percentage and decrease in crude-protein percentage from Series A to D. The Guinea Grass is a relatively dry type of fodder and for this reason is often preferred for equines. In protein-

percentage, if a difference greater than 9 per cent. of the mean value is taken as significant, the Para Grass is decidedly the best, followed closely by Elephant Grass. The mean protein-percentages of the two canes are very low, in part due to the rapid drop in nitrogen-content in Series D as a result of the development of the sugar-canes. The high nutritive value of Para Grass is a fact that is already acknowledged by the farming community. Dairymen in the locality even maintain that changing the ration of their milch cows from other roughages to Para Grass increases both the milk-yield and the butter-fat percentage. Unfortunately, this particular fodder is an obnoxious weed in arable land, and it is for this reason that it has not been more widely cultivated, but is generally limited to localities utilized solely for pasturage. Some authorities [4] state that the nodes can pass unharmed through the digestive tract of animals and ultimately under suitable conditions begin to sprout. This does not appear to be true of cattle in the tropics, as shown by the following experiment. The dung from working oxen fed on Para Grass was collected once a day for a fortnight and carefully elutriated with water over a fine sieve. The solid material remaining on the sieve was examined, and in no case was there any sign of undigested knots or seeds of the Para Grass. To make quite certain, the collected solids were then sown in semi-sterilized soil contained in nursery boxes, and every effort was made to try and induce sprouting of the Para Grass, but without success. The fallacy that this grass can pass undigested through healthy stock has probably arisen from the fact that in feeding, a portion of the fodder falls to the floor of the byre and gets swept up with the dung. It is certain that under such circumstances the Para Grass can survive in a manure heap for long periods, and ultimately begin to grow again when the manure is applied to arable land. Some simple experiments in the composting of Para Grass proved this statement, and indicated that the key to the effective decomposition of this grass lies in chaffing. A comparative trial was started in which the capabilities of decomposition of the following four types of basal material were tested:

(1) Young chaffed Para Grass
(2) Old chaffed Para Grass
(3) Young unchaffed Para Grass
(4) Old unchaffed Para Grass

In each case the material was thoroughly soaked in a mixture of water, urine, and cow-dung, was given a light dressing of lime, ammonium sulphate, and superphosphate in the proportions of 4 : 3 : 2 [10] and made up into a compost heap 15 ft. long by 5 ft. wide at base, and 5 ft. high. The amount of humification resulting is fairly accurately reflected in the weekly temperature chart recorded overleaf:

The heaps were opened at the end of ten weeks, and the decomposition in both chaffed heaps was satisfactory, being a stage more advanced in the young material than in the old. Subsidence in these heaps was very much greater than in the unchaffed produce, which was practically unaltered, and gave a fair percentage of sprouts on being planted in nursery beds. Old runners were obviously more resistant to rotting than the young fresh shoots.

Temperature in °C. at Centre of Compost Heap

Period	Chaffed		Unchaffed	
	Young Shoots	*Old Shoots*	*Young Shoots*	*Old Shoots*
	I	II	III	IV
7th day . .	58	55	33	30
14th day . .	53	51	33	30
21st day . .	45	40	31	30
28th day . .	42	36	30	29
49th day . .	36	32	30	29

A certain amount of sprouting occurred on the outside of all the heaps; this was thickest in the early stages and in the unchaffed produce; the number of surface sprouts surviving at the time of opening the heaps was relatively small. Thus, provided certain precautions are taken, Para Grass can be thoroughly decomposed by the ordinary technique used for making activated composts [10, 11, 12]. If the heaps are turned over a couple of times during the manufacture to ensure that the surface-layer is also fully rotted, there need be no risk of sowing Para Grass on to arable land when the dung from the byre goes out to the field in the form of activated compost. Experiments have now been started to ascertain whether this grass can be as effectively treated by the ordinary system of making farmyard manure in the cattle-pen.

This question has been discussed at some length as, provided the danger of spreading this grass among arable crops is eliminated, it appears to be a particularly promising fodder. One way of effectively avoiding this dissemination risk would be to inaugurate a system of controlled rotational grazing instead of using the Para Grass for soiling. As it has been shown that there is no danger of spreading the Para Grass in the dung, and as carting the cut grass from one part of the land to the next would be eliminated, the field of Para Grass could be successfully isolated from the rest of the farm. The danger of spreading the grass by other means is reckoned to be slight. The grazing practice would be along the lines recommended by Wilsie and Takahashi for Elephant Grass [13] whereby the grazing of the crop is permitted only when the grass has reached the stage of development at which it would normally be cut for soilage. The stock is confined to one small section for a few days at a time and then moved on to the next, thereby preventing the trampling from having any permanent ill-effect on the stools, and yet ensuring that most of the herbage is eaten so as to encourage ratooning. Judging from its growth-habit, Para Grass should be even better able than Elephant Grass to thrive under a grazing treatment. Pasturing is, of course, only practicable with dairy or beef animals, and the soiling system would have to be followed for working oxen.

Discussion

Of the six grasses tested, the Para Grass is outstanding as, under humid conditions of soil and climate, it combines most of the essential

features of a good perennial fodder crop, namely, ease of propagation, high productivity, excellent nutritive quality and palatability, general hardiness, and ability to exclude extraneous weed-growth. It gives only poor returns during prolonged dry seasons, and it has a second more serious drawback in the risk of dissemination to arable land, where it becomes an obnoxious weed. In consequence, it is recommended for use only in localities that can be effectively isolated from valuable arable land. This isolation may be achieved either by the observance of certain precautions in the manufacture of the farmyard manure, or by utilizing the crop on a system of controlled rotational grazing. In consideration of its many sterling qualities, Para Grass has now been included in a yield trial along with Guatemala Grass, Uba and Co. 213 Canes. Of the other varieties, the Guatemala Grass is considered to be a good all-round performer of average nutritive quality. It is admirably adapted to local conditions of climate and soil. In Trinidad, Elephant Grass must be condemned on account of its susceptibility to fungal infection. It may be possible to segregate a resistant strain, which, if it maintains the many good features that have made Elephant Grass so popular in other countries, would certainly have great cropping possibilities. The Co. 213 is superior to the Uba, which in the past has been one of the favoured perennial fodders sown in Trinidad. The Coimbatore Cane is undoubtedly worth a trial on any new areas that have to be planted in a cane crop required for fodder. The Guinea Grass is a variety that cannot be recommended as a general-purpose soilage crop for local conditions.

The variety, the height of cutting, and the length of the period between harvests, all influence the regeneration-habit of the ratoon-crops. It is possible by adopting an appropriate harvesting technique to combine rapid ratooning with multiple tillering and vigorous stool-development. With most varieties this will coincide with a cutting-rotation of approximately 3 months and herbage mown some 6 to 10 in. above ground-level.

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Typical stools of the individual grasses taken twelve weeks after harvest. This is reckoned to be approximately the correct time to cut them for fodder, as on a three-month rotation it is possible to combine fair nutritive quality, high yields, and longevity

THE DEVELOPMENT OF LIVE STOCK IN TANGANYIKA TERRITORY

I. ACTUAL AND PROPORTIONAL WEIGHTS OF THE VARIOUS PARTS OF THE BODY OF ZEBU CATTLE

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WITH PLATES 3, 4

THERE are few, if any, places in the world where meat costs less than it does in Tanganyika Territory, and this fact should offer a big incentive to any commercial organization to investigate the possibility of utilizing Tanganyika stock for the raw material of a meat industry. Among the first things such a firm would require would be a full description of the type of stock, and of the weights and proportional distribution of the tissues and organs of the animals.

In Tanganyika there are approximately five million cattle [1], but owing to the fact that two-thirds of the Territory is infested with tsetse flies, the cattle population works out at about 40 per square mile of 'fly-free' country [2]. Furthermore, in much of this fly-free portion, East Coast fever is enzootic and keeps the cattle population below this concentration, with the result that some areas are very grossly overstocked whilst others carry a very sparse cattle population. Stock from the different areas will therefore vary greatly in size and condition.

Owing to the seasonal rainfall, periods of good grazing alternate with long intervals of drought. In the dry season the animals lose a large proportion of the weight which they gained during the period of good grazing [3], and so the rate of growth is very slow, and in the overstocked areas the animals never reach their potential maximum development. In some areas overstocking, together with food and water shortage, becomes so acute that thousands of stock die annually from starvation.

Owing to the spread of tsetse flies, progressive soil erosion, and the increase in the proportion of land under cultivation, overstocking is tending to become more widespread. There is thus a very definite surplus of stock that could be used for a meat industry with advantage to the remaining cattle population.

In the native social community the position of live stock differs considerably from that in civilized countries. To the native, the possession of live stock is the means of acquiring prestige amongst his fellow natives. Cattle are so bound up with social customs, expecially marriage transactions, that the native develops a profound love for them, and places on them a regard far in excess of their monetary value. In past periods of famine the natives have been known to die of starvation rather than kill their already half-starved cows.

This reluctance of the native to sell his stock, and particularly his female stock, is gradually being overcome through education and contact with civilization. As the native is educated to need more and more

articles from other countries, the need of cash will become more general and he will be encouraged to sell more of his stock. This change would take place the sooner if a ready market existed for every class of animal. Any firm opening a meat factory may anticipate the availability of a fairly large annual supply of stock.

The object of this investigation was to find out the weights and proportional distribution of the tissues in the cattle slaughtered in the Mpwapwa abattoir during a period of twelve months. The animals brought to this abattoir are representative of the average type sold in the cattle market of the Territory. In size they are mid-way between the larger Masai oxen and the smaller cattle from the overstocked Usukuma areas.

The stock markets are the collecting foci of the cattle-producing areas, from which traders purchase stock for transport and re-sale to the cattle-consuming areas. At present the poor-conditioned, stunted, or half-starved cattle are refused by the traders, and so the stock sold in the markets represents the better class of animal.

No fattening-up for the butcher takes place, of course, and the animals slaughtered and measured during the past year do not represent fat stock but merely those in better condition. In this important respect the figures to be presented differ from those obtained by workers in other parts of the world, where only fat animals have been investigated.

The cattle to be found over the greater part of Tanganyika are of the hardy zebu breed. This is a small breed, with a large hump and short horns. Usually they have narrow sloping hind-quarters, but are fairly deep-chested and possess a relatively large heart-girth. The skin is of no more than medium thickness, and covered with short smooth hairs, which may be of any colour. The quality of the meat, as judged by that from the early-maturing English breeds, is poor, and the amount of inter-muscular fat is very small, so that no 'marbled' joints can be obtained. The amount of fat in the carcasses varies considerably with the season and also with the age of the animal. Usually, too, there is little internal fat.

Owing to the presence of a large Mohammedan following amongst the native population, all animals in public abattoirs are slaughtered according to the Mohammedan laws, i.e. by cutting the throat cleanly to the spinal column.

This is the best method of bleeding an animal, and the result is that very little blood is left behind in the blood-vessels of the carcass. In this method of slaughter the blood spurts out with such force that it is often impossible to collect it completely, and to estimate the amount of blood in the body.

In the tables below the various headings are self-explanatory, but the following need a few qualifying remarks:

The *head* is weighed with its skin, but after the tongue and horns have been removed; it is severed from the body between the atlas and the cranium.

The *tail* does not represent an absolutely constant fraction, since some butchers prefer to leave a few inches attached to the carcass, whilst others sever the tail at the rump. The 'tail' is weighed without its skin, and for the weighings recorded in Table 2, it was removed at the rump.

The heading *feet* includes everything below the hock and knee-joints.

The *hump* is the result of a musculo-fatty development of the rhomboideus muscles and consists of layers of muscle interspaced with layers of fat. It is the only 'marbled' piece of meat in the body. The hump varies greatly with the condition of the animal, and may be a foot or more in height, or not larger than a man's hand. Fig. 3 (Plate 4) shows a longitudinal section through a good type of hump. In the present investigation it was removed as neatly as possible so as to leave the carcass, over the withers, the same shape as in a humpless breed of cattle.

In hot countries it is impossible to keep meat for any length of time and so the animal is usually cut into portions almost at once and eaten within 48 hours of slaughter. All weights for the carcass are 'hot' weights therefore, as the splitting of the carcass is done whilst this is still hot. The cut, dividing the side into fore- and hind-quarters, is made between the 10th and 11th ribs, so that three ribs are left on the hind-quarters.

Except in the larger European communities of this Territory the carcasses are not jointed as in Europe, but the butcher just cuts off a kilo as required. For this reason no figures could be obtained showing the proportions of the various 'joints' in the carcass.

During the year, 313 head of stock were slaughtered in the Mpwapwa abattoir. The slow rate of growth, and the fact that the beasts were not brought to the slaughter-house by the breeder, prevented any accurate determination of their ages. For the purposes of this article the animals are grouped according to the number of permanent incisors they were showing.

The distribution of the various types of stock slaughtered during the investigation is shown in Table 1:

TABLE 1. *Animals Slaughtered in Mpwapwa Abattoir 1934–1935*

	Males	*Females*	*Total*
Full-mouth stock	120	27	147
6-tooth stock	40	4	44
4-tooth stock	67	8	75
2-tooth stock	43	4	47

These figures illustrate with what reluctance the native will part with female stock; when he does so it is because the animal is either barren, or gives insufficient milk for rearing a calf. Occasionally he will sell virgin heifers, but he hates selling anything he knows is capable of breeding and rearing offspring, and will only part with such stock as a last resort.

The average weights of the various tissues are given in Table 2. The figures presented in this table show the relative changes in the organs with increasing age, and also what differences can be expected between male and female cattle. In the mature zebu, as was found by Hammond [4] for British breeds of cattle, the carcass-weight, head, and hide are heavier in the males than in the females. The reverse is true of the suet fat and tongue. Hammond found the stomachs and intestines heavier in the females than in the males, but this does not appear to be so for the zebu breed.

TABLE 2. *Average Weights of Carcasses and Individual Tissues (lb.)*

Type of stock	*Full-mouth stock*			*6-Tooth stock*			*4-Tooth stock*			*2-Tooth stock*		
Sex	*Both sexes*	*Males*	*Females*	*Both sexes*	*Males*	*Females*	*Both sexes*	*Males*	*Females*	*Both sexes*	*Males*	*Females*
No. recorded	*147*	*120*	*27*	*44*	*40*	*4*	*75*	*67*	*8*	*47*	*43*	*4*
Fore-quarters	128·2	130·2	119·0	113·7	114·5	106·5	108·4	109·2	106·7	91·5	90·1	106·4
Hind-quarters	132·2	133·4	126·7	122·6	122·5	124·1	114·0	114·7	108·1	100·1	98·6	116·1
Carcass	260·4	263·6	245·7	236·3	237·0	230·6	224·4	223·9	214·8	191·6	188·7	222·5
Head	26·42	26·98	23·86	25·10	24·73	28·75	24·14	24·3	22·80	22·43	22·7	19·50
Horn	1·68	1·64	1·86	1·26	1·28	1·10	1·27	1·27	1·24	0·76	0·79	0·41
Tongue	2·19	2·17	2·28	1·90	1·95	2·20	1·94	1·94	1·97	1·48	1·52	0·96
Tail	1·50	1·55	1·28	1·26	1·28	1·06	1·20	1·21	1·11	0·90	0·92	0·69
Hide	31·55	32·13	28·98	30·79	31·11	27·50	30·03	30·54	25·70	25·02	25·30	21·87
Feet	10·60	10·16	12·92	10·43	10·33	11·47	10·01	10·09	9·31	8·78	8·8	8·52
Hump	5·90	6·11	4·95	4·80	4·74	5·36	4·21	4·21	3·89	3·80	3·79	3·85
Heart	2·14	2·21	1·80	1·90	1·87	2·20	1·91	1·85	2·48	1·64	1·65	1·51
Liver	7·09	7·16	6·78	7·26	7·18	8·11	6·83	6·86	6·60	5·90	6·00	4·81
Spleen	1·78	1·85	1·50	1·70	1·71	1·51	1·42	1·60	1·17	1·29	1·30	1·10
Lungs	7·35	7·45	6·89	6·80	6·97	4·06	6·49	6·55	5·73	5·55	5·54	5·64
Kidneys	1·38	1·38	1·38	1·25	1·25	1·24	1·19	1·18	1·27	1·04	1·03	1·15
Suet fat	3·80	2·77	8·33	3·18	3·24	2·61	3·10	3·10	3·15	1·62	1·51	2·89
Caul fat	4·07	4·14	3·76	2·77	2·77	2·75	3·20	3·24	2·88	1·78	1·82	1·38
Stomachs and intestines	34·12	34·53	32·30	32·60	32·82	30·37	30·56	30·83	28·31	29·02	29·28	26·80
Contents of alimentary canal	84·35	84·36	84·31	75·80	75·66	77·15	64·23	64·01	66·05	55·10	55·10	55·07

The average carcass-weight is seen to be very small and about 260 lb. for an adult animal. Of the 120 full-mouthed males slaughtered, 10 had a carcass-weight of over 350 lb., and averaged 381·1 lb. As will be seen by reference to Table 3, these animals gave a higher carcass-yield than the smaller animals, possessed more internal fat, and had a smaller percentage of offal.

The carcass-weight varies in the full-mouthed stock from 190 to 495 lb., and that of the hides ranged from 20 to 50 lb. It will be seen that the figures in Table 2 confirm the statement of Lichtenheld [5], who quoted Mannleitner, that 2-year-old oxen would reach up to 106 kg. carcass-weight and that 5-year-old oxen might go up to 200 kg.

The hump, which is not met with in Europe, when taken from a fat animal, boiled, and eaten cold, is a delicious food, but when taken from a poor animal, it is tough and unappetizing. The weight of the hump in these studies varied from 2 to 18·7 lb. Lichtenheld quotes 11 kg. as the weight of a hump from an Ugogo ox.

In these full-mouthed cattle we find that the hind-quarters are slightly heavier than the fore-quarters. The carcass-weight, with the hump left on and with the kidneys and kidney-fat not removed, is divided into 50·8 per cent. hind-quarters and 49·2 per cent. fore-quarters when the cut dividing the two is made between the 10th and 11th ribs. The hind-quarters thus form a higher proportion of the total carcass than would at first be expected; the percentage is only slightly below that for improved breeds. For South African stock exported to London, Fourie's figures [6] show the hind-quarters as representing 51·1 per cent. of the carcass, whilst for Grade European X Zebu cattle in Kenya I have shown that the hind-quarters represent 51·8 per cent. of the total carcass [7]. It is difficult to compare these figures with those given in the standard American publications, because the fore- and hind-quarters are divided between the 12th and 13th ribs.

As weigh-bridges are not installed at either the abattoirs or stock markets in this Territory, no exact live-weights could be obtained, and so the tissues cannot be expressed as a percentage of the total live-weight. From weights recorded at the Veterinary Laboratory, however, the cattle of this Territory vary in weight from large Masai oxen, averaging about 800 lb. when in good condition, to the small, stunted, and badly fed animals of the worst overstocked areas, which may weigh as little as 400 lb., even when apparently mature and in fair condition. The average weights of full-mouthed cattle bought in the stock markets would be about 500 lb. live-weight. Figs. 1 and 2 (Plate 3) show average full-mouthed oxen. In only 48 of the full-mouthed cattle recorded in Table 2 was it possible to record the weight of the blood in the body; the average weight of blood in these 48 animals was 18·13 lb., and their average carcass-weight 251·6 lb.

Since the carcasses and organs were all weighed hot and immediately after removal from the animal, the loss due to evaporation and cooling was very little. If we take the losses involved during slaughter, skinning, opening, and cutting up the carcass as approximately 1 per cent., we can calculate from the weights of the organs and the carcass the total live-

weight of the animal slaughtered. If we do this with the average figures obtained for full-mouthed stock of both sexes, the average live-weight is 510 lb.—a figure which wide practical experience confirms. By using this average live-weight, the proportional distribution of the various tissues has been determined and is set out in Table 3, together with the corresponding figures found by Hammond [4] for the average of all British breeds of cattle.

TABLE 3. *Weights of the Organs, &c., of Zebu Cattle, expressed absolutely and in terms of Live-weight. Comparison with British Cattle*

	Zebu cattle				*British cattle*
	Full-mouthed cattle		*Full-mouthed, with over 350 lb. carcass*		*Steers*
	Weight of organ	*Weight as per cent. of live-weight*	*Weight of organ*	*Weight as per cent. of live-weight*	*Weight as per cent. of live-weight*
	lb.		lb.		
Live-weight	510	100	700	100	100
Carcass	260·4	51·1	381·1	54·4	64·6
Head and horns	28·1	5·5	34·7	4·9	3·93 (head and horns, feet)
Feet	10·6	2·1	11·8	1·7	
Hide	31·6	6·2	43·6	6·2	6·7
Tongue	2·2	0·4	2·7	0·4	0·8 (tongue, tail)
Tail	1·5	0·3	1·7	0·2	
Hump	5·9	1·2	12·0	1·7	..
Heart	2·1	0·4	2·9	0·4	2·55 (heart, liver, lungs)
Liver	7·1	1·4	8·8	1·2	
Lungs	7·4	1·4	9·3	1·3	
Kidneys	1·4	0·3	1·6	0·2	..
Spleen	1·8	0·3	2·0	0·3	..
Stomachs and intestines	34·1	6·7	44·3	6·3	..
Contents of alimentary canal	84·4	16·5	91·3	13·0	..
Caul fat	4·1	0·8	9·4	1·3	..
Suet fat	3·8	0·8	9·5	1·4	..
Blood	18·1	3·5	25·0	3·6	2·3
Loss	..	1·1	..	1·5	..

The average zebu ox is less than half the weight of the average British steer, and a good zebu ox compares in size only with the smallest of the British breeds. Hammond has shown that the smaller animals in a given breed yield a lower percentage of carcass than do the larger animals of the same breed. This fact is also clearly demonstrated for zebu cattle in Table 2. It is to be expected, therefore, that the carcass of zebu cattle will not only be smaller, but that it will also represent a smaller proportion of the total live-weight than it does in British breeds.

The animals recorded by Hammond were cattle fattened for the Smithfield Show and therefore were better finished and carried more adipose tissue than the cattle recorded at Mpwapwa.

In the zebu cattle, the head, hide, and feet form a very much higher proportion of the total animal than they do in the British breeds recorded by Hammond, or in the beef-breeds exported from America, Australia, Argentina, and South Africa. The same applies for the heart, liver, lungs, and blood; and is probably also true for the stomachs and intestines, but Hammond's figures do not represent these organs freed from their contents so completely as do the present series. The internal and external fat deposits are much greater in the European breeds of cattle than in the zebu.

The average carcass in the Territory does not carry the finish required by the English markets. Generally there is a lack of subcutaneous fat, although in the older and better-conditioned oxen the carcass may be covered with a thin layer of fat. Further, the fat of the zebu carcass is most often yellowish in colour, which is to be expected in grass-fed animals. The meat is often dark, a result of long walks in search of scanty grazing. Figs. 4 and 5 (Plate 4) show a moderately good carcass.

Carcasses from the Tanganyika breed of native cattle could therefore find no place on the English market. They are better suited for a local canning or extracting industry, for conversion into fertilizer or feeding-stuffs for animals, and for the preparation of medicinal extracts from glands and liver. The lower percentage of fat in the carcass makes the local stock particularly suitable for these industries, especially the canning industry.

During the twelve months in which these figures were collected, 120,790 cattle were sold in the Tanganyika markets, realizing £103,762 10*s.*, i.e. an average price of 17·18*s.*, the range being from 5*s.* to 65*s.* per head, according to the market, the season of the year, and the type of stock.

The average price of the hides to the butcher for this period was between 4*s.* and 5*s.* each. If we take the average carcass-weight as 200 lb., which is less than that found at Mpwapwa, then the cost of 100 lb. of carcass is approximately 6·5*s.*, inclusive of the value of the internal organs, all of which are eaten by the native. In other words 1 lb. of carcass costs ¾*d.*, and nowhere in the world, so far as I can ascertain, does meat cost less.

Summary

A description is given of the zebu stock, which is the breed found throughout practically all the cattle areas of Tanganyika Territory. The position of the stock in the native community is discussed in its relation to the marketing of live stock.

Figures are given to show the average live-weights of the zebu cattle, and of the weights of the various organs in the body. The type of carcass yielded by these animals is described, together with the uses to which these carcasses are suited.

The average market price of over 120,000 stock sold during the period of investigation was 17·18*s.* The cost per lb. of carcass was ¾*d.*

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FIG. 1.

FIG. 2.

Typical Zebu oxen of 500 lb. and 550 lb. live-weight, respectively

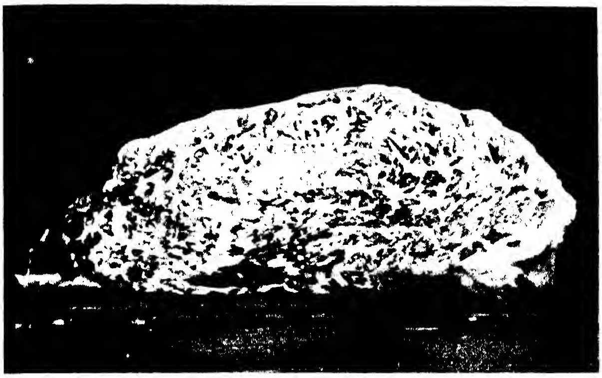

Fig. 3. A good hump cut longitudinally

Fig. 4. Fig. 5.

A good carcass from a Zebu ox

TECHNIQUE OF DIGESTIBILITY TRIALS WITH SHEEP AND ITS APPLICATION TO RABBITS

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WITH PLATE 5

Introduction.—In the work carried out at this Station on the nutritive value of grassland herbage, a large mass of data has accumulated in connexion with the feeding-value of the fresh crop, and of hay, silage, and artificially dried grass. Examination of the literature shows a dearth of accurate figures for such foodstuffs under conditions existent in the British Isles, though the work of Woodman at Cambridge [1] has added much to our knowledge of the feeding-value of fresh grass.

The composition and digestibility of most farm-grown foodstuffs is fairly constant, since they are fed mainly at the stage of maturity, and thus may be classified with a certain degree of accuracy. With grassland herbage it is otherwise: as it passes through its various stages of growth it is altering continuously in composition; its nutritive value depends on the stage of growth at which it has arrived. Hence a chemical analysis is not in itself sufficient for the determination of the feeding-value. This depends also on the proportion of the foodstuff which can be digested. By feeding an animal with a known weight of a feeding-stuff of known analysis and collecting and analysing the dung, it is possible to determine how much of the feeding-stuff is digested by the animal.

Technique.—The animals used for this work are sheep, the early experiments at this Station being carried out on Suffolk-half-bred-cross wethers, and the later and greater part of the work on Kerry-cross wethers (Kerry ewe–Southdown ram). Two Ryeland-half-bred-cross wethers (the half-bred being the usual Border Leicester on Cheviot) have also been used. No differences have been noted in individuals or between the breeds. When new sheep have been brought in for experiment, they have usually had a short period in the digestibility crates, in order to get them accustomed to the confined quarters and the feel of the harness. On such occasions no trouble has been experienced with either feeding or harness. The sheep are weighed before and after each trial, and fed on a ration at the plane of maintenance.

The experimental ration is fed to the sheep in a preliminary period before the proper feeding-period begins. The length of the preliminary period varies according to the time it takes for the animal to eat its ration freely, and may be cut down to two days. The sheep are then placed in the digestibility crates and equipped with harness. The experimental period, during which the ration is accurately weighed, starts the next day. The uneaten residues, if any, are collected each morning before the first feed is given. The dry-matter content of these residues is determined, and the composite sample made up from the whole of the residues in the experiment is analysed.

Owing to the lag in the passage through the alimentary tract, a period of forty-eight hours has to be allowed before the first collection of excreta takes place. When the last experimental feed has been given, there will still be two days' excreta to be collected. During these two days the sheep receive the same amount of food as they did during the experimental period.

Sampling.—Succulent foodstuffs, such as grass and silage, are weighed out daily, and a representative sample of 200 gm. is taken for dry-matter determination. The daily dry-matter samples are mixed at the end of the trial, and a complete foodstuffs-analysis carried out on this mixed sample. For silage, samples of the fresh material are taken daily for nitrogen-determination, and the total nitrogen ingested is calculated from these figures, and compared with the figure obtained from the dried sample. The loss of nitrogen in drying may vary considerably with the nature of the fermentation that has taken place in the silage.

With foodstuffs which will keep without change other than a slight variation in moisture-content, such as hay or dried grass, all the feeds for the whole trial are weighed out at the same time and stored in scrim bags. At the same time a sub-sample is taken for moisture-determination and subsequent analysis.

In summer the faeces are weighed every day, and nitrogen is determined in duplicate on 5 gm. samples of fresh faeces, which are thoroughly mixed by pounding them in a mortar. At the same time, for greater ease of sampling, an aliquot part equal to one-tenth of the total weight of the well-mixed fresh faeces is weighed into a flat-bottomed tin, and is put into a drying-room at 40° C. After all the samples have been collected, they are taken out of the drying-room, allowed to come to constant moisture-content in the laboratory, weighed, ground, and mixed thoroughly in the same way as the foodstuff. During winter the excreta collected on two successive days are mixed and treated as one sample.

The urine is collected daily, starting with the first day of the experimental period, and the nitrogen is determined on 5 c.c. portions. One-twentieth of the volume voided is taken each day, and is stored between chloroform and toluene. This composite sample is, where necessary, analysed for mineral constituents at the end of the trial.

Latterly the urine has been allowed to run away, since it is not needed unless the nitrogen or mineral balance of the animals is to be determined. This is not normally done, as it seems certain that accurate data for a balance trial of this type can only be obtained in long-period experiments, whereas the digestibility trial will give accurate results with an experimental period of 8 up to 14 days.

Equipment.—The construction of the digestibility crates used is shown in Plate 5. The inside of the crate is covered with 'Uralite', and a galvanized-iron grid is let into the floor. Below this is a lead-lined funnel which connects with a pipe passing through the bottom of the crate. The urine passes down this tube into a Winchester placed underneath.

The feeds are weighed out into boxes which slide into the front of the crate, and can be removed easily for the collection of the uneaten residues.

Distilled water is provided in a trough.

The sheep are fitted with a stout leather collar, which is attached to the crate by a length of chain. The dimensions of the crate and the length of the chain are such as to permit of free movement without allowing the animal to turn right round or get its hind legs off the grid by more than a few inches. No loss of urine has been noticed with the crates. The sheep are quite free to lie down, and spend most of their time in that position.

The faeces are collected in a special waterproof bag, which is attached by a webbing harness that causes no chafing. The bag is opened and closed by means of a 'lightning fastener', which passes down the full length of the median line of the bag. The faeces can thus be removed quite simply without unfastening the harness or detaching the bag.

No trouble has been experienced with any of the sheep chosen for experiment. Several of them have been continuously in the crates for periods of two months without any apparent effect on health or appetite. Special care must be taken of their feet, as the sheep are apt to become footsore unless the horn is cut down systematically. The Kerry-cross wether has been preferred merely from a practical standpoint, as no difference in the results has been noticed between the different breeds. The only digestive disturbance noted during the whole of the trials was due to the feeding of frozen mangolds. The sheep have varied in weight between 95 lb. and 120 lb., and the ration fed has varied between 2 lb. and 3 lb. of dry-matter per day. The live-weight has been maintained without exception while on experiment.

Determination of digestibility.—The object of the digestibility trial is to determine the amount and composition of the food and solid excreta. The part of the food which has been digested is then found by deducting the constituents of the faeces from those of the original food.

The following tables show how the balance-sheet is constructed. A sheep was fed daily for 10 days with 4 kg. of silage containing 23·13 per cent. dry-matter, and during the 10 days it was on trial there was a total yield of 2,240 gm. of air-dried faeces, containing 94·78 per cent. dry-matter.

The chemical analysis gave the following composition for the dry-matter of the silage and that of the air-dried faeces:

	Moisture	*Ether extract*	*Crude fibre*	*Crude protein*	*N-free extract*	*Organic matter*	*True protein*	*Ash*
Silage	..	5·18	24·99	18·22	42·54	90·93	9·21	9·07
Faeces	5·22	5·95	14·60	18·00	38·53	77·08	16·83	17·70

The amounts digested are calculated thus:

	Dry-matter	*Organic matter*	*Ether extract*	*Crude fibre*	*N-free extract*	*Crude protein*	*True protein*
	gm.	gm.	gm.	gm.	gm.	gm.	gm.
Intake—silage	9,252	8,413	479	2,312	3,936	1,686	852
Output—faeces	2,123	1,727	133	327	863	403	377
Digested	7,129	6,686	346	1,985	3,073	1,283	475
Amount digested per cent.	77·05	79·47	72·23	85·86	78·07	76·10	55·75

The figures in the last row are termed the 'coefficients of digestibility'.

It will be seen that the assumption is made that the whole of the dung consists of undigested food. This assumption is, of course, not correct, for the faeces always contain small quantities of substances which are metabolic waste products.

Metabolism experiments to determine digestibility are important, in that they are the only means by which a direct measure of the amount of any given food utilized by the animal body can be obtained. Efforts that have been made to determine the availability of a food *in vitro* have been successful only in the case of the protein. This has been effected by artificial digestion in acid gastric juice, and has served to determine the total quantity of protein which is digestible. Such determinations tend to measure the true digestibility in the digestive tract rather than the *effective* digestibility as measured by animals. The literature shows that the *in vitro* methods nearly always give coefficients which are higher than those obtained by animal experiments. This is, of course, due to the presence in the faeces of metabolic residues not directly derived from the food.

Attempts have been made to determine the amount of metabolic residues in the faeces by feeding a nitrogen-deficient ration. Kellner [2], working with herbivora, suggested a value of 0·4 gm. nitrogen per 100 gm. of organic matter digested. Pfeiffer [3] carried out a number of experiments with pigs. In the first period the pigs received a normal ration of barley-meal, in the second period a diet that was practically nitrogen-free, and in the third one containing completely digestible protein. In the second period he found that the whole of the faecal nitrogen was soluble in pepsin-hydrochloric-acid solution (gastric extract). The figures he obtained with pigs agreed with Kellner's value for herbivora. The work was then repeated, using goats. The amount of metabolic nitrogen per 100 gm. of organic matter digested was found to be 0·51 gm., with a range of 0·43 to 0·76 gm.

Morgen *et al.* [4], feeding a nitrogen-free ration to sheep, found that the average excretion of metabolic nitrogen was 0·57–0·64 gm. per 100 gm. organic matter digested. Crowther and Woodman [5], using sheep, obtained an average value of 0·52 gm. metabolic N per 100 gm. of organic matter digested.

Kellner [2] had tried to find the amounts of nitrogen remaining undissolved in artificial digestion of fodder with acid gastric juice, and found that these were lower than the amounts of nitrogen excreted in the dung of animals fed with the same fodder. It was assumed that the difference between the artificial digestion and the animal digestion was a fairly accurate measure of the quantity of nitrogen passing from the body to the faeces, i.e. the residues of metabolism. Kellner [6] makes no use of these figures in his book, and states that as there are no methods of estimating the metabolic residues in the faeces with certainty, the assumption has to be made that all nitrogen found in the faeces must be due to undigested food.

Pfeiffer [3], however, concluded from his experiments that the nitrogenous products of metabolism must be taken into account in determin-

ing the digestibility of the protein in animal experiments. Experiments were carried out to determine the digestibility of certain feeding-stuffs, (i) with animals, (ii) by artificial digestion, and (iii) with the value obtained in the animal experiment corrected for the nitrogen-containing metabolic residues. This last-mentioned value was obtained by digesting samples of the fresh faeces with 200 c.c. of pepsin solution at blood-temperature for 24 hours, with gradual addition of HCl, until a concentration of 1 per cent. was reached. The solution was filtered, washed with water, alcohol, and ether, and the nitrogen determined on the residue. The nitrogen soluble in the pepsin solution was considered to be due to metabolic residues. The figures are set out in the following table, together with those obtained by artificial digestion as determined by the modified Stützer method [7], using pepsin followed by a pancreatic extract.

TABLE 1. *Digestibility Coefficients of the Crude Protein of some Feeding-stuffs as determined by Different Methods* (*Pfeiffer* [3])

	A *Old Method animal experiments. No correction for metabolic residues (Average of 2 goats)*	B *Animal experiments. Correction applied for metabolic products in faeces (Average of 2 goats)*	C *Artificial digestion. Stützer method* [7] *using pepsin and pancreatin*
Period 1	64·31	78·55	79·43
,, 2	75·35	84·60	85·59
,, 3	74·95	86·35	86·78
,, 4	76·29	88·68	89·17
,, 5	79·59	90·07	89·31
Hay	64·31	78·55	79·43
Peanut cake	89·63	92·41	93·56
Dried beet (Period 3)	58·70	83·25	81·88
Lucerne hay	76·29	88·68	89·17
Dried beet (Period 5)	67·87	88·12	81·88

The values for the individual foodstuffs are calculated from the results obtained with the mixed rations fed in Periods 1 to 5. There is good agreement between the values obtained in the artificial digestion and the values obtained in the animal trials when corrected for metabolic residues in the faeces.

The figures obtained at Jealott's Hill when feeding a ration of artificially dried grass at the plane of maintenance are given in Table 2.

TABLE 2. *Digestibility Coefficients of Artificially Dried Grass obtained by Different Methods*

(Average of six sheep)

Animal experiments uncorrected for metabolic residues	*Animal experiments corrected for metabolic residues*	*Artificial digestion. Sjollema-Wedemeyer method* [8]
63·30	76·24	76·95

The pepsin-HCl-soluble nitrogen in the faeces, which was assumed to represent the nitrogen due to metabolic residues, gave an average value of 0·34 gm. per 100 gm. of dry-matter intake, with a range of 0·31–0·40 (0·56 gm. per 100 gm. organic matter digested, with a range of 0·48–0·67). Apparently, if there is a difference of 12·0 to 15·0 units between the digestibility coefficients obtained by artificial and by animal experiments, the correction of the animal figures for metabolic residues in the faeces holds good. In view of some of the figures obtained at Jealott's Hill and also by Woodman [9] at Cambridge, it would appear, however, that there is not always such a considerable difference between the apparent and the true digestibility coefficients.

TABLE 3. *Digestibility Coefficients of Crude Protein of Pasture Herbage*

(Stated as percentages)

Date of cutting	A *Artificial digestion*	B *Animal digestion*	*Column A – Column B*
April 27 Cambridge (Woodman)	83·5	79·3	+4·2
May 14 ,,	85·1	85·4	−0·3
June 1 ,,	81·7	81·1	+0·6
June 18 ,,	82·4	78·4	+4·0
July 9 ,,	80·1	77·1	+3·0
August 3 ,,	78·5	76·6	+1·9
August 24 ,,	81·3	78·9	+2·4
September 14 ,,	85·1	83·4	+1·7
October 5 ,,	84·5	84·0	+0·5
November 29 ,,	78·1	81·3	−3·2
October 2–10 Jealott's Hill	75·4	81·0	−5·6
,, ,, ,, ,,	78·5	77·2	+1·3
,, 17–25 ,, ,,	72·1	75·8	−3·7
		Average	+0·5

The application of the factor for metabolic residues would certainly produce anomalous results in the above figures.

In order to accept the digestibility coefficients obtained by correcting the figures from animal experiments for nitrogen due to metabolic residues, two assumptions have to be regarded as valid. These are, firstly, that as the protein has defied solution in the animal digestion, it will also be indigestible in the faeces when treated with pepsin-HCl solution, and secondly, that the nitrogen due to metabolic residues is soluble in the pepsin-HCl.

It is well known that whole maize and whole grain when fed to sheep frequently appear unchanged in the faeces. There is no reason to suppose that other foodstuffs with a high fibre-content, such as grass at a mature or hay-stage, is much more easily digested. The lignified cells can be seen clearly in the faeces of sheep, apparently quite unaltered. It is probable that the protein is protected in some degree by the presence of this indigestible material. This may be the explanation of the high digestibility of the protein in concentrates poor in lignified fibre, and of the difference between the protein-digestibility of young grass and of

grass at a mature stage. The protein from the latter is surrounded by tougher and more fibrous cells than that of the concentrates and the young grass.

The dried and *ground* faeces from animals fed on such fodder are, however, taken and further subjected to the action of pepsin-HCl under optimum conditions. It is not unreasonable to suppose that some of the residual food-protein which has escaped solution in the gut is now brought into solution. With reference to the effect of fineness of grinding, the following figures (Ashton, unpublished data, Jealott's Hill) are of great interest, as affecting the amount of pepsin-HCl-soluble nitrogen in a foodstuff:

TABLE 4. *Effect of Fineness of Grinding on the Pepsin-HCl-Soluble Nitrogen in Grassland Herbage*

Size of mesh:	$\frac{1}{4}$ in.	$\frac{1}{8}$ in.	$\frac{1}{16}$ in.	$\frac{1}{32}$ in.	$\frac{1}{64}$ in.
Nitrogen soluble in Pepsin-HCl (Wedemeyer) per cent.	1·11	1·54	1·57	1·70	1·76

S.E. mean of 3 . . . . 0·0116
Significant difference . . . 0·037

It is easy to see the possible effect of the fine state of division of the ground faeces on the nitrogen that is found to be soluble in the subsequent treatment with pepsin-HCl.

From the foregoing figures it will be recognized that a definite figure cannot be accepted for metabolic nitrogen for all rations. Morgen and co-workers [4], and Mitchell and Hamilton [10] have shown that the roughage-content, together with the amount of dry-matter present, could alter the figure, so that it varies with the plane of nutrition.

It would therefore appear that the effective digestibility of the protein, as obtained directly by animal experiments, is the most suitable figure to use for practical purposes. It is a measure of the net utilization of the protein by the animal—in the sense that it represents the difference between the nitrogen ingested and that voided in the faeces, which, for an animal in nitrogen-equilibrium, is equal to the nitrogen passing from the blood-stream into the urine—whereas the artificial method is not. Furthermore, in no case have the corrected values been used in official calculations of food-values.

Starch equivalent and protein equivalent.—The best possible criterion of the energy and fattening value of a feeding-stuff is the 'starch equivalent'. This is not a theoretical figure, but a figure based on results obtained by direct practical experiment. These values were used by Kellner [6], and are based on the energy-content of the foods. Experiments were carried out to determine the fat-producing capacity of different feeding-stuffs, and the pure constituents thereof. Table 5 shows the data on which Kellner's formula for calculating starch equivalents was based.

A correction has, however, to be made for a loss of energy during the metabolic processes. In dealing with the concentrates and feeding-stuffs of low fibre-content, the starch equivalent may be worked out directly, applying Kellner's 'value number' (*Wertigkeitsfaktor*), but for roughages

it is customary to make a correction varying regularly with the percentage of total crude fibre in the food between 4 and 16 per cent. Where the amount is 16 per cent. or more, a deduction of 0·58 of starch equivalent is made for each 1 per cent. of total crude fibre. The factor falls in value with the total crude-fibre content of the fresh food between 16 and 4 per cent., and when it is 4 per cent. or less, the deduction is 0·29 of starch equivalent for each 1 per cent. of total crude fibre.

TABLE 5. *Kellner's Data for Calculating Starch Equivalents*

From	*Fat produced*	*Factor*
	gm.	
1 kg. (digestible) protein	235	0·94
1 kg. ,, fat from oil-cakes	598	2·41
1 kg. ,, fat from grain	526	2·12
1 kg. ,, fat from hay and straw	474	1·91
1 kg. ,, starch	248	1·00
1 kg. ,, crude fibre	253	1·02
1 kg. ,, sugar	188	0·76

A typical example is given below, showing how, if the digestible nutrients of a feeding-stuff are known, the starch equivalent may be calculated:

15·12% digestible true protein × 0·94	= 14·21%	starch equivalent.
3·32% digestible fat × 1·91	= 6·15%	,, ,,
33·21% digestible nitrogen-free extract } 14·55% digestible crude fibre }	= 47·76%	,, ,,
	68·12%	,, ,,
Deduct 18·38% crude fibre × 0·58	= 10·66%	,, ,,
	57·46%	starch equivalent

That is to say, 100 kg. of this feeding-stuff is equivalent to 57·46 kg. of starch measured in terms of fat or energy production.

It will be noticed that the value for 'true' protein has been used throughout in the calculation of starch equivalents, according to Kellner's formula. Some doubt exists as to the correct figure to use in the case of silage, where there is always some break-down of the original 'true' protein.

The 'true' protein has been determined both in the feeding-stuff and the faeces by precipitation with copper hydroxide, according to Stützer [11].

For measuring the nutritive value of a foodstuff the starch equivalent must be supplemented by the protein-equivalent value. This is a figure suggested by the Departmental Committee for the Rationing of Dairy Cows [12], and consists of the mean of the values for the percentages of digestible crude and digestible 'true' protein.

There is considerable doubt nowadays as to the true value of the protein-equivalent figure. It seems certain that non-protein nitrogen may replace a part of the 'true' protein nitrogen in the ration without affecting the performance of the animal. Ammonium compounds [13,

14, 15] have been used as well as more complex nitrogenous substances, such as urea [16], and it is possible that in the near future the present-day conception of the nutritive value of nitrogen in the ration will have to be modified; it may prove that the total-nitrogen content is the best measure of the feeding-value of the nitrogenous compounds in the material in question. The work carried out to date on this question still requires confirmation.

Digestibility trials with rabbits.—All the digestibility trials quoted in the tables have been carried out with sheep as the experimental animals. There have been occasions when only small supplies of material have been available, insufficient for a complete trial with the sheep. It was thought that if rabbits provided a true measure of the digestibility of a food, as compared with the sheep, the technique of determination would be simplified, and materials, such as pure species of pasture plants, of which only small supplies may be available, could be tested.

Four trials were carried out with rabbits in 1933. The floors of the boxes consisted of wide-mesh netting, through which the faeces dropped to a close-mesh netting, placed at an angle, so that they rolled to a trough at the side. A tray was placed beneath the lower mesh to catch the urine, which ran into a beaker. The tray was washed down daily with distilled water.

The trials were carried out on three samples of grass from different fields, and on one sample of marrow-stem kale. The trials ran concurrently with sheep trials on the same materials.

The results obtained are compared in the following table:

TABLE 6. *Comparison of Digestibility Coefficients obtained with Sheep and Rabbits receiving the same Material*

	Grass 1		*Grass 2*		*Grass 3*		*Marrow-stem Kale*	
	Sheep	*Rabbit*	*Sheep*	*Rabbit*	*Sheep*	*Rabbit*	*Sheep*	*Rabbit*
Dry-matter	77·66	63·40	73·10	63·02	72·18	62·75	81·74	82·92
Organic matter	80·72	63·68	76·47	63·69	76·03	62·95	85·03	82·66
Ether extract	55·47	45·86	45·85	41·02	55·10	51·18	68·44	72·10
Crude fibre	83·97	46·88	78·39	50·12	78·25	50·96	74·32	54·93
N-free extractives	81·18	67·25	77·52	66·84	76·53	64·86	84·46	88·00
Crude protein	80·96	78·95	77·18	76·74	75·77	76·23	88·03	86·44
True protein	79·59	76·97	72·52	74·83	74·14	74·00	83·94	83·62

It is obvious that apart from the crude and 'true' protein coefficients there is a very poor agreement between the two animals in the trials with grass. Except for the crude-fibre digestibility there is good agreement in the kale experiment. As the crude-fibre content of the grass averaged 22 per cent. and that of the kale was 11·5 per cent., the depression of the digestibility of the fibre was not due to the different proportion of fibre in the diet. This low power of digestion of the fibre is evidently characteristic of the rabbit.

It may be concluded that rabbits do not offer a true picture of the

digestibility of grass as determined with sheep, except for the crude and 'true' protein values.

Possible use of indicator substances in digestibility trials.—Preliminary experiments have also been made in the use of indicator substances. The ratio of iron to the constituent under question in the ingested food and in the faeces affords a method of calculating digestibility coefficients without the actual measurement of the weight of fodder fed or the weights of faeces voided. It is necessary to know that the samples of the foodstuff and of the faeces are truly representative of the whole amount fed or voided, respectively.

It was found difficult to get any useful figures if the iron in the food was used as the indicator, since the amount present was small, and in consequence the accuracy of estimation was relatively low, and the ratio to any of the constituents in question is too wide. It is hoped in the near future to use an *added* indicator, such as a compound of chromium or titanium, which would be added at a predetermined rate to the foodstuff, and the ratio of it present in the food and in the faeces determined analytically.

If it is possible to evolve a simple technique, such as has been done in Sweden [17], it should prove a simple matter to obtain data on the digestibility of various crops at outside centres without undue trouble. All that is required is to ensure careful weighing out of the foodstuff fed and of the indicator used; careful mixing, so that the whole of the added material is ingested; and a technique for the collection of the faeces which will ensure that they are representative of the output over the experimental period.

Summary

The technique of digestibility trials with sheep is outlined, together with the methods adopted for calculating the digestibility coefficients and the starch and protein equivalents of different foodstuffs.

The correction of the protein-digestibility coefficient by making allowance for the metabolic nitrogen in the faeces is discussed, and reasons are advanced for retaining the uncorrected figures. The comparison of rabbits with sheep as instruments for determining digestibility has shown agreement only in the values for the protein. The rabbit does not digest fibre as efficiently as does the sheep, and values obtained with the former cannot be applied to the latter animal.

The possibility of using indicator substances in digestibility trials has been explored.

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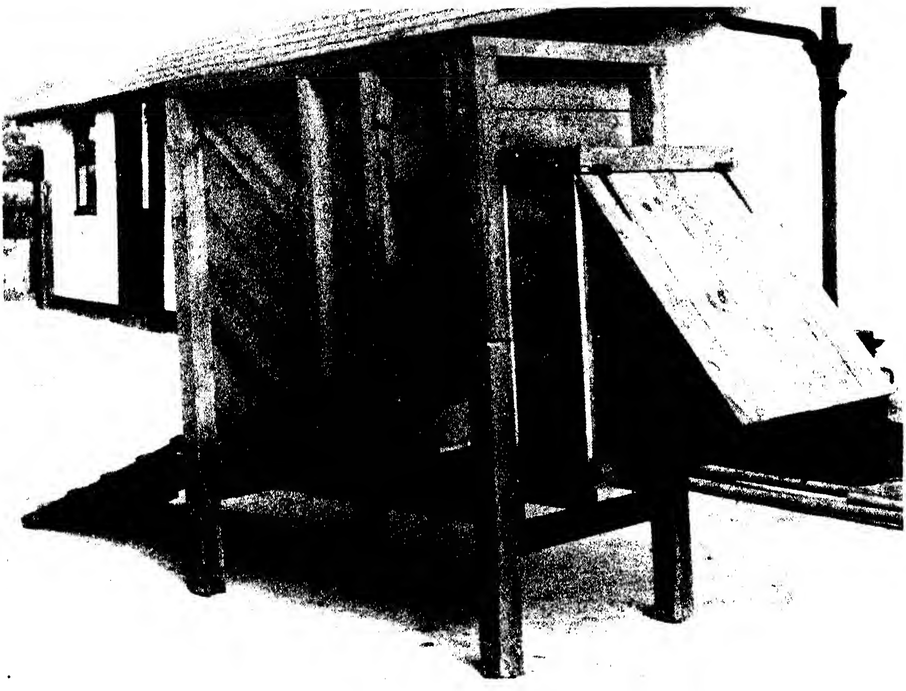

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Addendum.—Since this paper was prepared, C. J. Watson and W. Godden have published results (this *Journal*, 1935, **3**, 346–50) showing that the rabbit and sheep are not comparable as instruments for determining the digestibility of foodstuffs. The results of our experiment, described on p. 33, thus confirm their findings. S. J. W., E. A. H., November, 1935.

FIBRE-FLAX CULTIVATION IN THE UNITED KINGDOM AND THE EMPIRE

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Introduction.—In the days of the spinning-wheel and the hand-loom the cultivation of flax was firmly established throughout Europe, for this fibre-bearing plant was well suited to European conditions and there were many uses, both domestic and industrial, for linen thread and fabric. At that time all the operations from sowing the seed to weaving the fabric were rural occupations of the farmer and his family.

Many of the old uses for linen remain, some have lessened in importance and other uses have arisen, but, in addition to these influences on demand, the course of English industrial development has had profound reactions upon the use of linen and, in consequence, upon European flax cultivation during the past two centuries.

Within this period, cotton, an imported fibre and thus alien to British agriculture, took first place among the cellulosic fibres of commerce, and goods manufactured from cotton became an important British export.

Such economic trends tended to drive flax cultivation and linen manufacture out of the main stream of agricultural and industrial development during a period of rapid change.

Survival of flax and linen in Ireland.—The survival of flax in Northern Ireland was favoured by the continuance of the system of small family holdings, and by the growth of flax-spinning by machinery, which became a highly specialized industry there.

By a process of slow transition the modern Irish linen industry, operating about one-third of the power-driven spindles of the world, and including all branches up to linen finishing and making up, grew up without losing its association with the Irish farmer, and this interest in local flax supplies preserved flax cultivation in Northern Ireland. Flax thus found a place in the simple crop-rotation of the Irish farmer.

Belgian flax.—Northern France and Belgium produced a high-grade flax crop, and the Belgian flax workers acquired great skill in judging these crops, in taking full advantage of the favourable conditions for retting or steeping flax that were found to exist in the River Lys, and in separating and cleaning the flax from wood and other non-fibrous tissue. Originally used for fine spinning by hand, this high-grade flax came to be used for machine-spinning to fine counts for cambrics and similar goods. In this fine trade Northern Ireland led the way, and became a large importer of Belgian flax. Flax-growing, with a specialized technique, became part of the system of cultivation in this area.

Increasing dependence on Russian flax.—The Scottish coarse-linen industry, which was large and of vital importance in the sailing-ship period, having little home-grown flax, early became a large user of Russian flax. Under the primitive Russian conditions, flax was an attractive cash crop to the peasants and their landlords, so Russia soon

outdistanced all other countries in flax production and became the principal exporting country. The Irish linen industry soon followed Scotland and supplemented its home and Belgian supplies with increasing quantities of Russian flax, which thus became the staple flax in all flax-using countries, its price regulating that of all other flax, whether home-grown or imported. With the growth of the jute industry in Scotland on the foundation of the older flax industry, the Scottish textile manufacturer became still more dependent on imported fibre, so that in the United Kingdom only in Ireland was the complete chain from the cultivator to the linen merchant to be found.

Flax production in Europe.—Over a long period, Russia, by supplying the bulk of European flax, had a depressing effect on flax cultivation elsewhere. In the decade 1862–71, during which Ireland had a peak of flax cultivation in 1864 of 301,693 acres yielding 64,506 tons of flax, the approximate position was as shown:

European Flax in the Decade 1862–71

	Average acreage	*Average tonnage*
Russia	1,500,000	180,000
Belgium and France	300,000	60,000
Ireland	222,000	35,000
Great Britain	20,000	3,500

The Irish linen industry, which consumed 45,000 t., probably used home-grown flax in the main.

The United Kingdom imported 10,000 t. of flax annually from Belgium and 50,000 t. from Russia, the Russian flax going mainly to Scotland.

By the decade 1882–91 the following position was reached:

European Flax in the Decade 1882–91

	Average acreage	*Average tonnage*
Russia	3,000,000	300,000
Belgium and France	200,000	47,000
Ireland	106,000	18,543
Great Britain	3,000	533

At this time, the United Kingdom consumed about 97,000 t. of flax, of which Scotland used about 61,000 t., mainly Russian, and Ireland 36,500 t. The imports from Russia were 60,000 t., and from Belgium 14,000 t.

The figures overleaf, for the period 1909–13, derived from the International Year-book of Agricultural Statistics, illustrate the position immediately before the Great War.

At this time the total requirement of flax in the United Kingdom was about 98,000 t. per annum. The home production was 11,400 t. in Ireland and 100 t. in Great Britain. United Kingdom imports from Russia were 69,000 t. and from Belgium 20,000 t. The average costs per

European Flax 1909–13

	Average acreage	*Average tonnage*
Russia	3,200,000	500,000
Belgium and France . . .	110,000	41,000
Northern Ireland . . .	53,000	11,400

ton of these flaxes for 1909–13 were, Russian £39, Irish £65, and Belgian £81. The Irish flax, intermediate in price and quality, was steadily being supplanted by fine Belgian flax on the one hand, and cheap Russian flax on the other.

Effect of the War.—The European war brought into prominence the important part which linen plays in the supplies of war material. Flax was required in huge quantities for the manufacture of tents, wagon-covers and similar heavy goods, linen thread was wanted for boots and other purposes, and hospital linen was required by the medical services. The progress of aviation and the growth of the Air arm introduced a new use for linen that soon overshadowed all others in national importance, for a fabric made from the finer yarns was found suitable, and became standard, for covering the wings of aeroplanes. The linen industry became fully occupied with the production of such military supplies. The difficulty of securing supplies of flax from the usual sources rapidly became a serious problem. Belgium again became the chief battle-ground of Europe and this cut off supplies of high-grade flax. Although Russia was allied with England up to 1917, war disorganized Russian agriculture and trade, and the difficulty of importing flax and flax seed via the Arctic Ocean was enormous.

In Northern Ireland the acreage in flax increased very little in 1915, was doubled in 1916 and 1917, and was almost trebled by 1918. The chief difficulty met with was in providing increased supplies of seed for sowing. The Northern Ireland farmer was wont to import his seed from the European flax-growing countries, chiefly Russia, thereby simplifying his operations by omitting to save his own seed, often a difficult matter in the Irish climate. The War disorganized flax-growing in Europe, made seed scarce, and importation difficult. It was not easy to get thousands of small Irish farmers to save their own seed satisfactorily. At this time flax cultivation for both seed and fibre was developed in England, but the great fall in prices that occurred soon after the War did not allow the industry to survive.

Post-war trends.—To-day Russia remains the country with the largest acreage under flax, but it has been passing through political and economic changes which render its ultimate position as an exporter of flax difficult to forecast. The area sown to flax in Russia is stated to be about 5 million acres, but the return in fibre appears to have fallen from 360 lb. per acre in the 1909–13 period to 200 lb. per acre in the period 1925–33, the tonnage produced thus remaining at pre-War levels.

Since Soviet Russia to-day aims at agricultural and industrial self-sufficiency, there seems little prospect that she will expand her production in order to increase her exports. A small margin of flax for export

at high prices may be thought more profitable, particularly as this may, at the same time, place the newly developed Russian linen industry in a favourable position, when compared with foreign linen industries depending upon Russian supplies.

The growth of Russian industry appears to be reducing the importance of Russia to western Europe as a supplier of primary products, such as wheat or flax. Russian industries are supplying their home market more and more with goods made from native primary products, and, if foreign markets can be secured for Russian manufactured goods, this course will be preferred to maintaining exports of raw materials. The trade returns are significant. They show that about 280,000 t. of flax were exported by Russia out of a production of 500,000 t. annually during the 1909–13 period, but with production again reaching 500,000 t. the average export was only 55,000 t. in the period 1925–9 and about 80,000 t. in the period 1930–3. This points to an increased consumption of flax in Russia itself of 200,000 t., i.e. over 80 per cent. of the entire Russian output is used at home. The shift of production and trend of prices are shown below (figures from the International Institute of Agriculture):

World Production of Prices of Flax

Period	*Production (1,000 metric tons)* U.S.S.R.	*Production (1,000 metric tons)* Other countries	*Price of ZK Livonian £ per ton in London*
1909–13	513	228	35½
1925–9	298	233	86
1930	440	190	51¼
1931	550	134	35¼
1932	500	98	45½
1933	560	128	51¼
1934	530	165	61

The broad picture is that before the War Russia produced more than two-thirds of the world's flax but used less than one-third.

During the years 1925–9 Russia used as much of her own flax as before the War, exporting the remainder, only one-fifth of the pre-War exports, at a high price. In the same period and in response to the same price-level, the rest of the world returned to its pre-War level of flax production, and the world outside Russia used about 290,000 t. of flax, drawing only about 60,000 t. from Russia. The increase in Russian production, although Russian exports increased only to 80,000 t., coinciding with the world crisis, oversupplied the flax market and forced down the flax production of other countries to a minimum of 98,000 t. in 1932. Although the production of the rest of the world has increased since 1932, this seems to be partly due to the limited export and greater retention of flax by Russia. Russia is now producing more than three-quarters of the world's flax and using two-thirds of it. Although the quantity of Russian flax exported is low enough to maintain flax prices, it is still imported to such an extent into the United Kingdom that it forms the chief source of supply. Unless home supplies of flax can be permanently

increased, the British linen industry will be too dependent on imported flax to benefit fully from the relative increase in popularity of flax as a textile fibre, which has been largely brought about by British industrial enterprise.

It is clear from the history of flax cultivation in the United Kingdom that a renaissance of flax-growing in Northern Ireland and Great Britain is the first condition necessary to establish home supplies of flax on an adequate and permanent foundation.

Post-War position in Northern Ireland.—During the decade 1921–30, in conformity with the general situation, the area under flax in Northern Ireland settled down to 33,000 acres, but when, in the general crisis, flax fell from £80 to £42 per ton in 1930, at this unremunerative level the area cultivated fell to 7,440 acres in 1931, 6,093 acres in 1932, and, with recovery setting in, 9,784 acres in 1933, 15,676 acres in 1934, up to 27,755 acres in the present year.

Attitude of the Irish linen industry.—In general, the dependence of the industry upon foreign supplies has been viewed with concern by the trade, and trade organizations have existed to foster home flax production for nearly a century. With the formation of the Linen Industry Research Association in 1919 under the auspices of the Department of Scientific and Industrial Research, the problem of the scientific development of home flax supplies was placed in the forefront.

By continuous research upon the economic botany of the flax plant and upon methods of fibre-extraction, it has been sought to place the home growers of flax in a relatively advantageous economic position. Such work will justify itself if it results in the establishment of a stabilized area of flax production in Great Britain and Northern Ireland of real significance as a source of supplies to the linen industry, rendering it less sensitive to price fluctuations brought about by variations in foreign supplies.

The Linen Industry Research Association and flax cultivation.—The main work of the Linen Industry Research Association is concerned with the manufacturing processes of the linen industry, but the association of research on flax cultivation with such work, rather than its independent prosecution by a purely botanical or agricultural organization, has had several advantages. The produce of the plant, in this case the flax fibre, having no direct application in farming, and being hidden within the stem of the plant, the value of the crop is not apparent to the unpractised grower, and the requirements of the linen industry may not be understood by him. The linen industry in N. Ireland, as the principal producer of fine linen, must have supplies of flax of fine and medium qualities, so research has been directed towards securing the production of these qualities at home, while reducing the costs of production to a minimum by mechanizing the methods of cultivation and fibre-extraction.

Pedigree seed.—The first requirement was the origination of pure lines of fibre flax to give uniformity in the plant, and hence in the fibre, and at the same time to give an increased yield in fibre per acre to the grower. So long as the Irish or British flax grower has to use sowing seed imported

from eastern Europe, he is in the same position as these producers of cheap fibre in regard to seed, and has only better cultivation to set against their low costs due to differences in the standard of living. Under the auspices of the Development Commission, J. V. Eyre began systematic work on flax selection before the War, which he continued as Director of Research for the Linen Industry from 1919 to 1926.

At first, since tallness of the plant was found to be an heritable quality, pure lines were originated from single selected tall plants. By 1930 the seed of this type, known as 'J.W.S.', originated by Dr. Eyre in 1911, had reached 650 t., or enough to sow 15,000 acres. This seed increased the yield per acre to the farmer by about 30 per cent. over the yield got from current commercial brands of sowing seed. For the linen trade this tall variety of flax had two disadvantages, the excessive length of the fibre strands gave difficulty with the mill machinery, and these strands were inclined to be coarse.

Meanwhile, A. G. Davin and G. O. Searle were investigating by statistical and other methods the inheritance and interrelationship of the principal characters of the flax plant. A method of estimating the proportion of fibre in the stem was worked out, in which the percentage area of fibre in a perfect cross-section cut half way up the stem, was measured on the magnified image of the section. It was found that four characters of the plant—length of stem, percentage of fibre, time of flowering, and number of seeds per capsule—were heritable. Accordingly, selections were made for high fibre-content as well as length of stem.

Plant-breeding on these lines involved much time and labour; in the case of one variety alone, 7,864 plants were measured for length of stem and 762 of these were sectioned before the selection of the single plant, which was to be the founder of the line, could be made. In this way the Liral series of flaxes, some of which are now available commercially, was originated. They have been included in official variety trials by the Ministry of Agriculture, Northern Ireland, for about ten years in some cases, and the advantage to the home flax grower can be realized from the following table:

Normal Yield of Flax Fibre per Acre

Variety	*Yield in stones* (14 lb.)
Commercial seed	30
J.W.S.	40
Liral Beatall	51
Liral Monarch	47
Liral Crown	48
Liral (unnamed)	58

Although the limit of increase in yield may now be in sight, research on heritable characters and selection based upon it can still provide strains to suit climatic and soil conditions and to give fibre of good quality. Besides this, re-selection and re-establishment are desirable after a strain has been in commercial use for some years.

Seed-bulking.—After any pedigree strain has been originated, it is necessary to establish some means of raising the bulk of the seed to a commercial quantity while maintaining the purity of the strain. Conditions in Northern Ireland, where flax-growing is undertaken by thousands of small farmers who are not accustomed to save seed, render it unpracticable to establish an organization for this purpose there.

It is not remunerative in the United Kingdom to raise fibre flax for seed only, so it has been found necessary to introduce the cultivation of fibre flax into Great Britain under the most favourable conditions for saving the seed and also securing a good quality of fibre. This was attempted, at first in Somerset, a central flax factory, closely following Belgian practice, buying flax crops from the growers and working them for seed and fibre. This factory succeeded in its principal object and established the commercial bulk of J.W.S. seed, which was sent in some quantity to various parts of the Empire, and later that of Liral Monarch, but the crops were not of Belgian quality, and the costly Belgian methods were not justified by the quality of the fibre obtainable. It was realized that extensive research work on the processes for obtaining seed and fibre from the crop was required, and in 1929, with the assistance of the Empire Marketing Board and the Government of Northern Ireland, an experimental flax factory was set up at the Research Institute, Lambeg, Co. Antrim.

The Belgian methods of handling flax were studied systematically with the object of retaining all the operations which appeared to be advantageous to the final product, but these processes were mechanized where possible, thus reducing the numerous and costly handlings of the material to a minimum. As a result of this work, the present position has been reached.

Operations in a modern flax factory.—The first operation, de-seeding the flax straw, is done by the process of 'rippling' or combing off the seed-bolls, as this method does not injure the straw or the seed. A de-seeding machine, embodying this principle, has been designed and constructed in which power-driven combs enter progressively deeper into the head of a layer of flax straw fed past the combs by means of a conveyor-belt, the throughput being 5 t. per day.

The seed-bolls are broken and conveyed without further handling to standard seed-cleaning machinery. The seed is then put through a simple seed-dryer, resembling the grain-dryers used in Canada; the seed then keeps without serious loss of germination until it is required for sowing next season, provided the storage is also dry.

The retting or steeping remains a bacteriological operation, but is done in large concrete tanks, holding 3 or 4 t. of straw, under controlled conditions of temperature, water-flow, and water-change. In Belgium the best straw is given a double retting in the River Lys, with an intermediate drying, but owing to the greatly increased handling, this is costly.

Drying after retting is best done in the open air; the bundles of straw are unrolled against a simple fence-work on the drying-ground, and drying is rapid, even in wet weather. The labour of opening the bundles for drying is also minimized. The best method of disposal of retting-effluent

is by irrigation over suitable land. Retting, by dissolving away non-fibrous connective tissue, loosens the fibre strands from the wood of the stem. The dried, retted straw is then passed through a breaker, to break the wood into short lengths. Fluted roller breakers of the usual type were investigated, but were discarded in favour of a new type of breaker, termed a lateral breaker, in which the layer of retted straw is fed continuously, the straws lying at right angles to the direction of feed, and being broken by parallel oscillating bars during their passage through the machine. Broken straw from this breaker can be picked up automatically by the belt-feed of an automatic scutching machine of the turbine type. The broken wood is knocked out in its passage past rotating blades in a cylindrical casing, and scutched fibre, i.e. fibre free from wood, is delivered at the end of the machine. A certain amount of tow, short fibre, is removed with the wood, and this is carried along on a conveyor-belt to a tow-shaker or separator, the wood and dust falling through a grid and being removed from the building by a dust-extraction plant. Owing to the improved methods of handling the straw and maintaining the parallelism of the stems, the proportion of tow is much reduced.

Location of central flax factories.—A centralized method of handling the flax crop for seed and fibre, such as this, should be established only in districts where conditions are favourable. In the first place the district must enjoy a climate, particularly at harvest, which favours seed-production as well as fibre. It is also desirable for fields to be large and fairly flat, favouring the adoption of mechanical pulling, instead of hand-pulling, at harvest. It is an advantage for a central factory to be able to draw its crops from a small number of large farmers, who are using modern mechanized methods of arable farming. With the use of pedigree seed, the factory should then receive large tonnages of flax crop highly uniform in quality, which can be given the most suitable treatment in retting and scutching. The eastern counties in Great Britain are most likely to possess these advantages, and the Linen Industry Research Association has begun to develop flax growing for pedigree seed and fibre there.

Experiments in Norfolk.—In 1931 H.M. the King was graciously pleased to have an experiment made with 3 acres of flax on the Sandringham estate. This gave the good yield of 40 stones to the acre, and afforded preliminary estimates of the costs of cultivation, fibre production, and value of the products.

The crop was transported to Northern Ireland and worked in the experimental flax factory there. The general result was so promising when compared with previous experience in Great Britain that arrangements were made for large-scale trials. The first of these was carried out in 1933 with a crop of 120 acres. The whole of the crop was baled in Norfolk and transported to the experimental factory at Lambeg, Northern Ireland, where it was de-seeded and processed for fibre under strict factory conditions. The broad result of the factory working was the production of 24 t. of flax fibre, which was sold for almost £2,000, over 12 t. of tow realizing nearly £300, and about 27 t. of seed realizing about £1,000. The flax growers received nearly £1,200 from the factory in

payment for crop, and omitting the baling and transport costs, the total costs were estimated to be about £3,000. A second large crop was grown in Norfolk in 1934, and 265 acres were planted in 1935. These crops have not been transported to Northern Ireland, but will be processed in a modern flax factory in Norfolk under the auspices of Norfolk Flax, Ltd., a private company formed for the purpose, the capital for which has been provided by firms in the linen trade.

The 1934 crop was de-seeded in Norfolk and the de-seeded crop stored; the de-seeding of the 1935 crop is proceeding, and the factory is now ready to carry on retting and scutching operations. In 1934 the drought injured the crop from the farmer's point of view, but in 1935, although conditions were again dry, with better selection of land and rather more favourable incidence of rainfall, an excellent crop has been secured, showing the good average return of 1·9 t. per acre to the grower. There is every reason to believe that the 1935 crop will yield an excellent supply of pedigree seed, and fibre of Belgian quality commanding a good price in the Belfast market.

Prospects in Eastern England.—Under present conditions the Norfolk flax factory could continue to pay attractive prices to the farmers and the area of flax in Norfolk and the Eastern Counties could be expanded very considerably. Expansion for this enterprise depends upon the market for pedigree flax seed in Northern Ireland. At present, flax prices are attractive and, if maintained, the Northern Ireland farmer would increase his acreage, particularly if he could be certain of obtaining supplies of pedigree seed from Norfolk or other suitable flax-growing areas. Even without much expansion in Northern Ireland, about 2,000 t. of pedigree seed would be needed to sow nothing but pedigree flax there, and an area of 10,000 acres of flax, worked on the central factory system to supply both seed and fibre, would be required to produce 2,000 t. of seed annually.

It would not be difficult to increase the acreage under the crop and, concomitantly, the facilities for de-seeding, but to extend the facilities for retting and scutching would require considerable constructional work and capital expenditure.

At the present time much interest is being shown in methods of fibre-extraction that would be alternative to bacteriological retting. The development of any method which would render retting unnecessary in the district where the flax is grown would simplify the central flax factory and facilitate expansion.

Research programme in England.—It must be emphasized that successful operation depends upon cultivation resulting in a crop which, as harvested, contains flax fibre of good quality in good yield, and upon fibre-extraction processes that are economical and not harmful to fibre quality. To ensure these conditions as far as possible, the Linen Industry Research Association has formed a branch Flax Research Institute at Flitcham Abbey, near King's Lynn, to which it has transferred its botanical and agricultural staff. This will enable Norfolk flax growers to get constant and prompt technical advice on flax cultivation, and the central flax factory to get technical advice and assistance on the problems

of de-seeding and fibre-extraction. The Flax Research Institute will study, under Norfolk conditions, such matters as suitability of soils, crop-rotations, manures, weed-killers, cultivations, and harvesting methods, besides continuing plant-breeding work and the establishment of improved strains of flax. In this way we may endeavour to equal and then surpass the products of Belgium and Northern France and establish the flax crop on its merits in the Eastern Counties.

Flax in Northern Ireland.—So long as we regard flax cultivation in Great Britain as a means of ensuring a supply of pedigree seed to Northern Ireland, the area of flax grown in Northern Ireland must always be at least four times as great as that grown in Great Britain, and Northern Ireland flax will be the principal home supply of flax fibre.

Mixed farming predominates and farms are small in Northern Ireland. To a large extent the holdings are self-contained and subsistence husbandry has not been displaced by purely commercial farming. For example, though a proportion of the potato crop is exported, much of this crop is used on the farm for food or fed to live stock. A good deal of the eggs, butter, milk, poultry, and meat is also consumed on the farms. Forage or green crops are grown, and there is a large production of hay to supply winter keep for the large numbers of cattle reared. In 1914 the areas of the principal crops in Northern Ireland were, in acres: oats, 334,846; potatoes, 170,225; turnips, 58,567; and flax, 40,580; in 1934 the areas were: oats, 279,789; potatoes, 137,321; turnips, 35,960; and flax, 15,676.

Flax is grown in an eight- or nine-year rotation, such as, roots, oats, hay, pasture, pasture, pasture, oats, flax; this safeguards against retention in the soil of the organisms of flax-wilt and other diseases. Since oats occur twice to flax once in this rotation, it may be supposed that flax could be increased in Northern Ireland to about half the area under oats, i.e. to 160,000 acres, without introducing any radical changes in agricultural practice.

The area of flax or any crop grown by the individual farmer is small, not more than one or two acres, and even in these there may be considerable soil variation. The Irish farmer now fully realizes the advantages which pedigree flax seed gives him, and how these advantages are secured without any changes in his existing practice. Any sudden changes in Irish flax cultivation could not be expected, but a systematic endeavour could be made to get the best out of the existing individual system by a careful study of the data of cultivation, leading to a classification of soils as to their suitability for flax, comparison of crop-rotations, incidence of weeds, and so on. The small Irish flax crops are all harvested by hand-pulling, and are usually steeped at once by the farmer himself in a flax dam, dug by a convenient stream. The suitability of the water in retting-dams varies enormously all over the country, and a difference in the water can make large differences in the value of the fibre from crops starting on level terms as pulled. A classification of available retting-waters to enable the best use to be made of them is highly desirable, and they could be used under less primitive conditions with proper means of effluent treatment.

After drying his retted flax straw, the Irish farmer takes it to a scutch-mill, where for a fee the flax fibre is extracted from the wood. The flax breakers and scutch-wheels are primitive machines, and it is probable that through research work better machines could be made available to improve both the yield and the quality of the flax fibre. Since the Irish farmer sells his own flax fibre, any improvement in scutching facilities is important to him. The provision of pedigree seed and of advice and assistance to the Irish farmer on the above lines should lead to a progressive development of Irish flax-growing, and call for a corresponding development in the Eastern counties in Great Britain to provide the supply of seed.

Empire flax.—The development of flax-growing in other parts of the British Empire is a further possibility that should be kept in view. The experience gained on the broad acres of Norfolk, where farming is highly mechanized, would seem to be readily adaptable to conditions overseas.

There should be no insuperable difficulty in the way of the British Empire supplying the world, outside Russia, with flax, and the home country growing a large proportion of the flax required by our own linen industry, if full advantage be taken of the results which systematic industrial research now provides.

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TREE-PLANTING IN THE SEMI-ARID AREA OF CANADA

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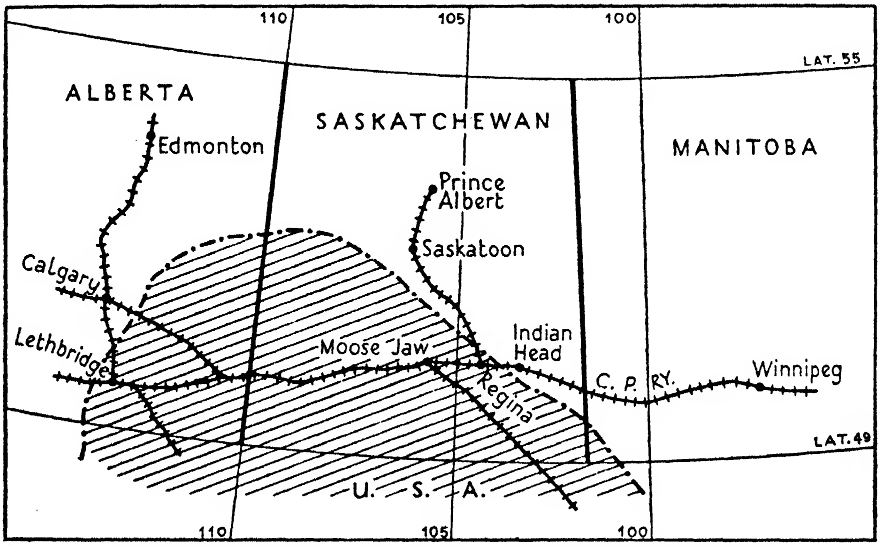
THE greater portion of the southern sections of the prairie provinces of Manitoba, Saskatchewan, and Alberta may be classed as semi-arid, for the average annual precipitation of snow and rain in these areas varies from 11 to 18 in., over a 20-year period. Temperatures will run as high as 105° F. in the shade in summer to −55° F. during winter. Spring usually starts the first week in April, and the ground generally freezes



SKETCH MAP OF CANADIAN PRAIRIE PROVINCES

The shaded area is most subject to extremes of drought.

in the first week in November. Precipitation during the growing-months from April to July will average about 9 in. in normal seasons. Seasons, however, are not always normal. We have just experienced four or five years of extreme drought.

It can be seen readily that climatic conditions are not favourable to tree-growth on the Canadian prairies. If we could be assured of 15 to 18 in. precipitation each year, tree-planting would not be a serious problem, but extreme and sudden changes of temperature and periodic recurrence of seasons of excessive drought present real difficulties to the planter.

Generally speaking, the soil throughout the prairies is rich in plant-food, and, given adequate moisture, it supports a heavy growth of native grasses and other perennial vegetation, against which trees have to compete. During seasons of poor rainfall the native vegetation persists and uses up so much moisture that a growth of trees cannot be successfully maintained on the same ground.

The prairie tree-planter, then, has to contend not only with unfavourable climatic conditions, but also with competition from the natural ground-cover. Experience has shown, however, that even in the driest areas trees suitable for shelter-belts, and also for the production of fuel and of fence-posts, can be grown if proper methods are adopted.

First of all the soil must be thoroughly prepared in order completely to eradicate the native grasses and other perennials, and to store up a reserve of moisture to give the young plantation a reasonable start. This usually requires two seasons. In the first season the sod is broken a few inches deep and then thoroughly worked. One season is sufficient to kill all the native plants. The following year the land to be planted is deeply summer-fallowed to open up the soil for the roots and to conserve moisture.

The next step is to select varieties that have been proved hardy and capable of withstanding drought when once established. The list of varieties suitable for shelter-belts, and for propagating in large numbers at reasonable expense, is very limited. It consists of: Caragana (*Caragana arborescens*), a leguminous shrub of Russian origin, exceptionally hardy and drought-resistant, which makes a dense shrubby growth to a height of about 20 ft.; Manitoba Maple (*Negundo aceroidis*), a native tree with a somewhat bushy tendency, which will grow to a height of about 40 ft.; Green Ash (*Fraxinus lanceolata*), a native, rather slow-growing tree, also very drought-resistant; the American Elm (*Ulmus americana*), a hardy native tree; native White Spruce (*Picea alba*); Colorado Spruce (*Picea pungens*); and Scotch Pine (*Pinus sylvestris*), of which there are many types, the one most suitable being propagated from seed secured in Finland or central Sweden. All these varieties can be grown successfully on the average upland prairie soils. In certain districts, usually associated with lighter soils, the water-table may be reasonably close to the surface (from 7 to 15 ft.), and in these districts many varieties of poplars and willows, in addition to the trees already mentioned, prove very satisfactory. The following figures of height-for-age confirm this statement:

Height-growth of Various Species from Measurements made at Indian Head, Saskatchewan

Variety	*At 10 years old*		*At 20 years old*	
	ft.	in.	ft.	in.
Manitoba maple	17	0	27	8
Green ash	10	6	22	6
American elm	8	6	19	2
Paper birch	17	0	28	0
Russian poplar	25	0	47	0
White spruce	3	0	16	4
Scotch pine	8	0	22	6
Jack pine	7	9	21	2
Lodgepole pine	5	8	20	1
Tamarack	14	0	28	0
Siberian larch	15	0	31	9

Up to the present, tree-planting on the prairies has been confined

principally to establishing shelter-belts and wind-breaks around the farm homes, gardens, fruit plots, and stables. Very few plantings have been made for the production of fuel or other wood materials.

These shelters usually consist of from two to ten rows of trees, and, in order to get benefit from them as early as possible, they are planted close together, i.e. about 4×4 ft. apart. This spacing is wide enough to allow cultivation between the rows for about three years, a period during which weeds must be kept from going to seed, and great care taken that grass does not become established. After about three years, growth will be sufficiently dense to cover the ground and shade out the natural vegetation. To prevent grass working into the belt from the outside, it is very important to keep strips of soil, at least 16 ft. wide, continuously cultivated along both inner and outer edges of the belts; these cultivated strips also provide a wide area for the feeding-roots and for the conservation of moisture.

In the districts most subject to drought it is almost impossible to start plantations during dry cycles, and therefore every advantage should be taken of seasons with normal rainfall to get the young plantations well established. Once they are established, belts of hardy varieties will stand up under very severe drought conditions.

The soil in the prairie provinces is particularly adapted to the production of wheat of the very highest quality, and this is the principal crop produced on the farms. For the production of wheat enormous acreages are under cultivation that are entirely open to the full sweep of the winds. Constant ploughing and cultivating for many years has worked out the natural fibre in these soils and has rendered them very susceptible to drifting. This condition is particularly aggravated during seasons of light winter snowfall and sparse rainfall. It is now not an uncommon experience for farmers to have the seed entirely blown out of the soil before it has a chance to germinate, or, even after germination, to find the young crop completely cut off or buried by the drifting soil.

The tendency for the soil to drift, coupled with the drought-hazard, has become an extremely serious problem and is causing the Government and those dependent on agricultural prosperity very considerable concern. Many remedies have been suggested; among others the planting of shelter-belts to protect field crops has been very widely discussed of recent years.

Unfortunately the problem is a comparatively new one and but few data are available at present to indicate whether shelter-belts might have the desired effects of checking soil drifting and conserving moisture, and, if so, whether such belts can be maintained economically. In certain cases, however, where a few individual farmers have already planted and established rather short stretches of field shelters, the results have been encouraging: the crops within the influence of the belts have shown decided increases in yields, and in some instances have been saved from soils drifting in the spring. It remains, however, to be determined whether a more general planting of crop-shelters will prove practical and profitable over larger areas. This will entail cutting up fields into smaller units of probably 40 to 80 acres, which, however, some farmers

think too small for the economical operation of the larger types of farm implements that are at present in general use.

Considerable sums of money have now been voted by Parliament to assist farmers in securing water-supplies, and in introducing new methods which, it is hoped, will ameliorate drought and soil-drifting conditions in the future. Part of this money will be spent in encouraging the systematic planting of field-shelters over comparatively large blocks, including several adjoining farms for demonstrational purposes. It is hoped that after a few years such demonstration areas will prove whether projects of this kind are economically sound or not.

In the meantime steps are being taken to increase the production of nursery stock on the two Dominion Forest Nursery Stations, from which over 150 million seedlings have already been distributed for the further encouragement of planting farm shelter-belts. The protection of vegetable gardens and fruit plots, although of vital importance in helping to make the farm a self-sustained unit, is not the only benefit derived, for in a territory that is almost devoid of natural tree-growth the aesthetic value of these shelter-belts in improving the amenities of the homestead is of equal if not of greater economic importance.

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PASTURE STUDIES VIII. IMPROVEMENT OF GRAZING LANDS IN EASTERN CANADA

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WITH PLATE 6

Introduction.—Eastern Canada comprises that section of the Dominion lying east of the Great Lakes and is divided into the five provinces of Ontario, Quebec, New Brunswick, Nova Scotia, and Prince Edward Island. It represents a total land area of 630 million acres, much of which is quite unsuited for agriculture, either because it is rough and rugged or its climate, in the northern parts, is quite unfavourable. Whereas the area of possible farmlands amounts to some 130 million acres, the portion at present occupied is approximately 49 million, of which slightly over 8 million are devoted to pasture.

Measured in terms of many European countries the whole of Canada is of recent settlement. The early settlers engaged extensively in lumbering, and it was not until the past century was well advanced that any great measure of permanent agriculture was established. Thus very few farms will be found where anything approaching intensive farming operations have been carried on for more than one hundred years.

As the forests were cleared away, the first use made of the land was for permanent pastures. Following the removal of the lumber, fire was employed to get rid of the brush, when the land was either left to seed itself naturally, or a sparse application of grass and clover seeds was scattered in the ashes. The ease of breaking up such lands eventually determined whether they would be utilized for cropping. Many fields that have never been broken, or only roughly cleared, exist in eastern Canada to-day, representing the great bulk of the so-called permanent pastures.

Until the past fifteen or twenty years, little thought was ever given to the pasture area beyond measures calculated to keep down tree and shrub growth. Even yet, on permanent pastures, it is quite the exception to find any well-ordered practice of fertilization and management. The impetus for the present interest in pastures is dictated in part by the favourable results obtained in other countries through the use of fertilizers, coupled with proper management, and in part by the very apparent falling-off in productivity of our grazing areas.

Space will permit only of a generalized discussion of the subject under review. Results of experimental work are still largely unpublished and therefore cannot be given. The phases dealt with most fully will include the natural features of the region, the animal population, types of pasture, and the organization involved in pasture-improvement work, together with a statement of the important projects that are under way.

Natural Features of the Region

Soils.—The soils of eastern Canada present a tremendous range in type. Practically all are of glacial origin, but they have been greatly

modified, through the centuries, by the many and diverse natural agencies affecting them.

Only a fair beginning has been made with systematic soil surveys. Both in Ontario and Quebec surveys have been made, but in each case they are concerned with specialized soil types, so that the information at present available does not warrant any attempt at definite zoning of any large territory.

The accompanying map (Fig. 1) is designed to present some idea of the major soil divisions and their location. For the provinces of Ontario and Quebec it is based on the genetic soil map of Canada, as prepared by the soils group of the Canadian Society of Technical Agriculturists. For the three Maritime Provinces the boundaries given are purely empirical, since no soil data are available. The four soil divisions represented on the map are:

1. Laurentian Upland Podsols.
2. Appalachian Upland Podsols.
3. Brown Forest.
4. Marine, Lake, and River.

The Laurentian and Appalachian podsols have a number of features in common. They each display the typical leached layer characteristic of true podsols; they are acid in reaction, and their upper layer consists of organic matter only slightly decomposed. Whereas fairly extreme acidity is found in each case, the lime-content of the former is notably higher, in spite of the fact that the Laurentians are not considered as fertile as the Appalachian. Laurentian podsols are formed from igneous rock, but the Appalachian are from sedimentary. A forest-cover of deciduous trees is found in the virgin lands of both areas.

The Brown Forest [1] soil regions are much less extensive than the podsols and represent a more fertile agricultural soil. Although these soils have undergone considerable leaching, they do not present the distinct ashy layer characteristic of the podsol. The iron, aluminium, and organic matter are fairly evenly distributed through the weathered mass of soil. As may be implied, their colour is a brownish hue, and the change, in this respect, is slight with increasing depth. In reaction they are neutral to acid, but, as a group, would generally be described as mildly acid.

The fourth group, designated Marine, Lake, and River soils, is a very diverse one, varying all the way from an almost purely organic to an inorganic colloid type. Thus they include mucks, gravels, sands, clays, and mixtures thereof. They are naturally associated with the water-courses of the country and frequently occur as long narrow strips bordering lakes and rivers. Muck soils are widely distributed, in areas varying from one to several hundred acres in extent. Although the total area belonging to this division is not large, some of the most productive farming districts are found within it.

Our detailed knowledge of these soils is too meagre to give much idea of their composition. In general, one may say that in the cooler parts the nitrogen-content is extremely high but in a very inactive state.

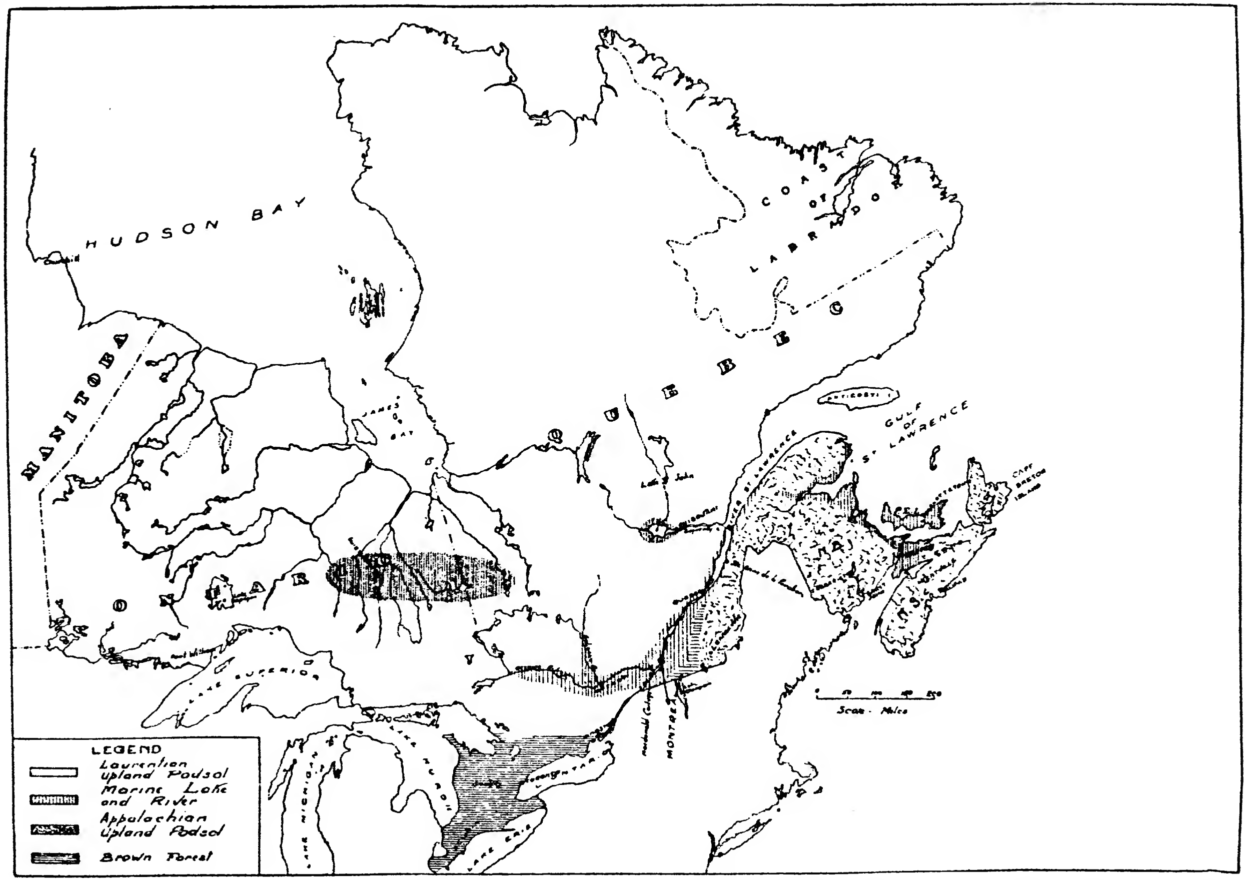

Fig. 1. Map of eastern Canada showing the main soil zones and the location of the stations referred to in the text.

Phosphorus is almost invariably a limiting factor in most soils of eastern Canada. Potash is usually present in fairly adequate quantities. Acid soils are widely distributed, particularly in those sections with a high rainfall. Limestone, in outcrops of high quality, occurs over most of this region, at intervals which permit of its use without undue transportation costs.

Climate.—The climate of eastern Canada presents some very decided pasture problems. Temperature and precipitation figures show a considerable range, varying generally from east to west, with cooler and more moist summer seasons prevailing under maritime conditions. Extremes of 100° F. or over are not uncommon in parts of western Ontario, but a much lower and more even temperature is characteristic of the Maritime Provinces and parts of Quebec. Precipitation figures—a combination of rain and snowfall—vary from 29·42 in. at Chatham in Ontario to 43·24 in. at Charlottetown in P.E.I., as an average for the ten-year period 1925–34. Particularly in the east, a considerable portion of the total falls as snow. The distribution of summer rainfall is fairly similar to that for total precipitation, but its effectiveness is greatly influenced by the high evaporation in the warmer sections.

The pasture season is one of four or five months, beginning in some sections early in May and in others not until June, and terminating in September or October. Seasons affect both the time that pasturing may begin and the evenness of herbage-growth throughout the year. In the early spring the nights are usually very cold, and productive stock that have been well housed and highly fed will shrink unduly if exposed to such conditions; even though the grass may have made considerable growth. After the long winter of inactivity, herbage-growth develops very rapidly in May and June, but is severely checked, in the warmer sections, by drought in July and August. This is followed by a second but minor peak in September.

Climate thus presents some real problems in handling pastures efficiently. Management aspects are greatly emphasized under such conditions. A well-grazed sward is difficult to maintain. Midsummer shortage must in many places be met by growing supplementary crops, and is generally overcome, in part, by grazing the aftermath from the meadows.

The Animal Population

Some account of the grazing-animal population will be of aid in visualizing the existing situation. Table 1 shows, in approximate numbers, the totals of milch cows, other cattle, and sheep, by provinces, together with the totals for eastern Canada and for the Dominion as a whole. Data are included in the table giving, by provinces, both the occupied and possible farm land. Some idea of the concentration of stock is made possible by a study of these figures.

Types of Existing Pastures

The acreage under pasture in the five eastern provinces, as shown in Table 2, is between one-sixth and one-seventh of the area of occupied

TABLE 1. *The Population of Grazing Animals for Eastern Canada in detail and Totals for the Dominion. Figures on available farm land to admit comparison (1931)*

	Milch cows	Other cattle	Sheep	Acres of Farm Land: Occupied	Acres of Farm Land: Percentage of possible occupied
P.E.I.	44,000	55,000	76,000	1,191,000	96
N.S..	108,000	113,000	195,000	4,302,000	65
N.B..	101,000	113,000	143,000	4,153,000	42
Que..	836,000	884,000	732,000	17,758,000	36
Ont..	1,098,000	1,339,000	1,035,000	21,978,000	39
Total	2,187,000	2,504,000	2,181,000	49,382,000	42
Canada	3,513,000	4,478,000	3,608,000	162,516,000	30

(From *Canada Year Book*, 1932)

TABLE 2. *Acreage devoted to Pasture in the Five Eastern Provinces as an average of the years 1930–4*

Prince Edward Island	221,018
Nova Scotia	770,184
New Brunswick	507,100
Quebec	3,213,820
Ontario	3,019,495
Total	7,731,617

farm land. The available statistics do not provide any information as to the kinds of pastures that are included in this total, nor is any precise information on this point obtainable from any other source. It will only be possible, therefore, to note the kinds of pastures that exist and give but a vague idea of their relative importance.

In the sense in which the term is used in the older countries, permanent pastures may scarcely be said to exist in Canada. The term is used with reference to rough areas, where the cost of breaking and seeding is, for the time being at least, prohibitive. They might much more logically be referred to as natural pastures. The total pasture area, as recorded in the table, may then be divided into two: those areas on tilled land which are used only temporarily for this purpose, and the natural pastures. Of the two, the latter occupies much the larger area.

Tilled pastures.—Tilled-land pastures are of the same general type throughout but vary somewhat in the herbage species seeded. They are almost always fields that have been used for hay-production for one or two years after seeding. The common practice is to break the sod and plant to a hoed crop, which is followed by grain and seeded down. After one or more years of hay, from one to four years of pasturing may follow. The mixtures of herbage plants used in seeding-down consist largely of timothy, red clover, and alsike in those districts where acidity is fairly high; this is modified where soils are less acid by the inclusion of alfalfa and a corresponding reduction in the amount of the other

legumes. In the absence of alfalfa in the mixture, the legumes are usually entirely absent by the time the pasture years are reached, and the sward is made up very largely of timothy. Depending on the district, the stand may become modified by the incursion of some of the common pasture types, such as red top, Canada or Kentucky blue, and wild white clover. In those districts where alfalfa can be grown, a much more useful pasture can be obtained, since this legume is longer-lived. It is exceedingly useful also inasmuch as its deep-rooting habit permits its continued growth during dry periods when few other herbage plants will make any contribution.

Pure stands of alfalfa are used to a limited extent in western Ontario for pasture. Sweet clover is also worthy of mention. It is used, however, more as a supplementary crop, the biennial form being planted in the spring and utilized for grazing in July and August of the same year. In some districts orchard grass is included, particularly in combination with alfalfa.

There is a slight but growing tendency to seed down with a combination mixture which, in addition to the more strictly hay species, includes some Canada or Kentucky blue, red top, and white Dutch clover. The use of wild white clover in a seeds-mixture can hardly be said to have begun.

Supplementary crops, such as maize, oats and peas, millet, and a variety of other annuals, are grown in those sections where the summer droughts are likely to be most severe. Closely associated with these is the practice of grazing the aftermath from the hay meadows. The hay crop is removed in June or early July, so that in early August the legume-hay meadows in particular furnish considerable grazing.

The direct fertilization of tilled pasture lands is not at all common. The hay meadows are quite commonly top-dressed with barnyard manure, and some residual effect carries over into the pasture period.

Natural pastures.—Natural pastures vary tremendously in their make-up and usefulness. On the one hand, there are areas so stony and rough that little opportunity is afforded for a sward to develop. A wise policy would have left such lands possessed of their native trees. These shade, on the other hand, into another class, still unproductive, where large moss hummocks (largely *Polytrichum spp.*) take possession of at least half the surface, and where hard-hack (*Spirea tomentosa*) still further crowds out species suitable for grazing. Possibly fifty per cent. of these pastures, however, provides sufficient opportunity for sod-formation and the growth of useful herbage to warrant some kind of treatment for their improvement.

Although comparatively little is yet known in any precise way about the characteristic species association on these natural pastures, a beginning has been made. On the podsols, where the acidity is relatively high, the dominant species is bent grass (*Agrostis spp.*). The order of the other common grass species is quite variable, but will most commonly be Kentucky blue (*Poa pratensis*), timothy (*Phleum pratense*), and red fescue (*Festuca rubra*). Wild white clover (*Trifolium repens*) is very widely distributed in associations of this type. A very common weed

grass in such districts is poverty grass (*Danthonia spicata*), found growing in high, dry, and infertile locations. The most prevalent pasture weed, particularly in the Appalachian podsols, is hawkweed, either the orange- or the yellow-flowered species (*Hieracium aurantiacum* or *H. florentinum*).

The species found on the brown-forest soils vary as between the east and the west. This is probably a climatic influence. In the more easterly region about the only difference found, as compared with the podsols, is a somewhat greater proportion of Kentucky blue, and a corresponding decrease in the poverty grass and hawkweed. To the west the proportion of Kentucky blue becomes much greater and that of the wild white clover distinctly less.

On the marine, lake, and river soils, and more particularly the heavier soils found in this group, Kentucky blue is usually the outstanding species. In some districts Canada blue (*Poa compressa*) takes the place of Kentucky. Wild white clover is not present to anything like the extent that it is on the higher and more acid soils.

With few exceptions, the productivity of all these natural pastures is very low. Grazed continuously, and at some seasons of the year insufficiently, they have been gradually, but surely, becoming less and less productive. More attention is now being focused on this type of pasture than on any other.

Research Work and Organizations Involved

Federal, provincial, and private organizations are concerned with pasture investigations in eastern Canada. For the most part, committees are formed at the various points composed of workers from different fields who have a definite interest in pasture problems. Other organizations bring together groups of provincial workers or inter-provincial gatherings.

The largest single organization engaged in pasture studies is the Dominion Experimental Farms. The central farm is located in Ottawa and one or more branches or sub-stations are to be found in each province of the Dominion. The more important sub-stations, from the pasture standpoint, in the east are those located at Lennoxville and Ste. Anne de la Pocatière in Quebec, Fredericton, N.B., Kentville and Nappan in N.S., and Charlottetown, P.E.I. The position of these can be seen in Fig. 1 (p. 53). A pasture committee at Ottawa directs and co-ordinates the pasture investigations at all these stations.

Working in close co-operation with Ottawa is the Guelph group at the Ontario Agricultural College, whose position in the western part of Ontario divides the field, and through the agricultural-representative system has a ready channel for distributing information and results.

In Quebec, apart from the federal undertakings, three groups are engaged in pasture investigations. The Provincial Department of Agriculture, through the Division of Rural Economics, is mainly concerned with disseminating information obtained from the more technical institutions; it does a great deal to keep alive a definite interest in pasture work. At Ste. Anne de la Pocatière, seventy miles below Quebec City, L'École Supérieure D'Agriculture fosters a pasture-investigation project.

The third group is that found at Macdonald College in the western end of the province. All the work in the province is generously supported by the Department of Agriculture, and a provincial committee helps to co-ordinate the various undertakings.

Apart from the federal stations in the Maritime Provinces, New Brunswick is the only one of the three, at present, actively engaged in pasture work. As in Quebec, its activities are more along the lines of extension. The following is a list of the more important lines of work now being pursued:

1. Trials with single varieties and strains of herbage-plants to determine productivity, palatability, and the effects of grazing and fertilization.
2. Study of mixtures of various grass and clover strains; results measured by clipping or grazing, or by both methods.
3. Breeding of pasture or dual-purpose pasture-hay strains of grasses and clovers.
4. Methods of improving natural pastures; use of fertilizers, lime, seed, and a variety of cultural treatments.
5. Methods of establishing permanent pastures.
6. Grazing management; rotational versus continuous grazing, single versus mixed stock, light versus heavy and variable rest periods.
7. Co-operative grazing experiments with farmers.
8. Pasture surveys, floral, ecological, and economic; study of floral succession following specific treatments.
9. Annual or supplementary pastures.
10. Nutritional features.
11. Soil aspects; delimitation of the larger soil zones; phosphorus relationships.

Although most of the accumulated data from these projects are at present unavailable, a few results have appeared. The improvement of natural pastures has received more attention than any other single phase. The work of Shutt *et al.* [2] with nitrogenous fertilizers and frequent clipping is well known. Nowosad [4] has discussed the value of mineral fertilizers on natural pastures in parts of Quebec.

Co-operative grazing experiments have been fairly widespread. Table 3 gives a summary of results with dairy cattle, published by the Quebec Department of Agriculture, which corresponds closely with those obtained in the Maritime. Crampton and Raymond [7] report on a three-year grazing trial with steers.

Pasture surveys are being fairly extensively made. Two publications, one by Newton and Nowosad [5], and one by Newton and Stobbe [6], have attempted to relate the existing flora to the soil type in parts of Quebec. Their work shows a wide adaptation of the natural species. A fairly complete list of the existing species is included.

In the nutritional field considerable work is in progress. Papers by Crampton [9] and Crampton and Finlayson [10] record results obtained when rabbits were used to evaluate both pure species and mixed herbage.

Soil zonation is receiving rather belated attention in different sections. Wrenshall and McKibbin [8] discuss some phases of soil phosphorus.

McConkey [3] discusses the use of herbage crops in eastern Canada, pointing out some of the difficulties inherent in the situation. The same author [11] shows some of the possibilities of improvement through the use of the new strains of grasses and clovers.

TABLE 3. *Summary of Results obtained in Grazing Trials with Dairy Cattle. Rural Economics Branch, Quebec Department of Agriculture*

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1931	283	799	$1.07	$8.50	$2.89	$11.39	$4.39	$7.00	40
1932	659	769	$0.80	$6.17	$1.30	$7.47	$3.56	$3.91	38·5
1933	712	873	$0.93	$8.11	$4.32	$12.43	$4.23	$8.20	37
1934	1,088	788	$0.94	$7.47	$3.95	$11.42	$3.82	$7.60	34

1. Year.
2. Arpents fertilized.
3. Increased milk per arpent in pounds.
4. Average return for milk per 100 pounds.
5. Value of increased milk.
6. Value of reduced feeding expenses and crops saved due to fertilizing.
7. Total increased receipts per arpent.
8. Charged cost of fertilizers.
9. Average gain per arpent.
10. Increased number of cow-days grazing per arpent.

Note: an arpent = 0·8447 acre.

Owing to lack of information, recommendations for the many diverse pasture problems that arise cannot be said to be in any way stabilized. For natural pastures there seems to be much more agreement of opinion and more experimental evidence on which to base advice. Where wild white clover is indigenous the use of a mineral fertilizer, such as a 0–16–6 at a rate of 500 lb. per acre, has been shown to give economical returns, or in some cases a phosphatic fertilizer alone has been used. Where wild white clover is not found then nitrogen is of considerable value, and from 300 to 500 lb. of a 2–12–6 is most frequently used. Figs. 2 and 3 (Plate 6) illustrate the effect of a phosphatic fertilizer where the incoming wild white clover has greatly benefited the sward.

In this account of pasture-improvement work in eastern Canada it has not been possible to present detailed results. Much the greater proportion of the projects have been under way for too short a time to warrant any general deductions. It has been the aim rather to picture the conditions and the detail of the machinery that is being applied to the task. Some of the important aspects of this region may, however, be summarized in conclusion.

The tremendous soil variation that exists points definitely to the necessity of a classification of the particular types on which work is being done. This phase, so fundamental to the investigations, should receive much greater attention.

The climate characteristic of eastern Canada presents a wealth of problems requiring solution. The pasture season, of four or five months, is short and much complicated by the unevenness of the output of herbage. This situation requires intensive studies of management and treatment-factors calculated to spread production over the season as evenly as possible. The question of supplementary crops will doubtless continue to be a necessity in many sections.

There is also the large field, as yet hardly touched, of breeding herbage-plants to meet the rather exacting conditions prescribed by the climate.

The nutrition studies that have been begun promise valuable information as applied to the whole pasture problem.

Really intensive pasture investigations over any considerable area can only be said to have begun about five years ago. With the attention now being focused on this problem, some really fundamental information should be forthcoming concerning the pastures of eastern Canada.

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Note: Free use has been made of the annual reports of both the Provincial and Federal Ministers of Agriculture, and also of the reports of the Experimental Farms from the Central and Branch Stations. Very useful progress reports, in mimeographed form, have been issued for each of the past few years by the investigators at Ottawa and Guelph.

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Photo. by Father M. Proulx

FIG. 2. Vegetation of a natural untreated pasture near Ste. Anne de la Pocatière, Quebec. The grass species are largely Agrostis

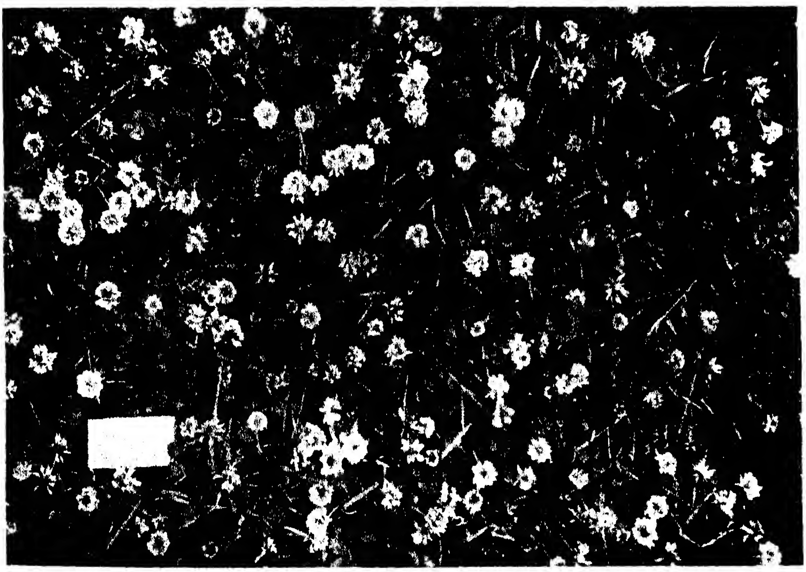

Photo. by Father M. Proulx

FIG. 3. The result of treating natural pasture as in figure 2, with 16 per cent. superphosphate at 500 pounds per acre. The wild white clover now dominates the sward

THE RATE OF LOSS OF EXCHANGEABLE LIME FROM NORTH WELSH AGRICULTURAL SOILS

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In North Wales, where the soils are generally developed from non-calcareous parent materials, the practice of liming is essential for the maintenance of fertility. This practice, which was formerly regular and extensive, has during the present century been generally neglected, with the result that the lime-status of many soils has fallen below the level necessary for fertility. Other soils, still containing sufficient reserves from former dressings, must eventually fall to this level in the absence of treatment. Soils of the first type are of frequent occurrence and respond readily to dressings of lime. Experience has shown that the lower limit for satisfactory lime-status in North Wales is in the region of 0·15 to 0·20 per cent. exchangeable CaO. It is, however, undesirable to allow soils to come to this low level before applying lime. The exchangeable lime should probably be about 0·25 per cent., or even higher, not only for the sake of yields, but also to maintain quality. Once a satisfactory lime-status has been reached it should be maintained by regular dressings of lime. The amounts and frequency of these will depend on the net loss of exchangeable lime from the soils under the system of farming practised. This loss consists of the lime removed by crops and drainage, less the additions in the form of manures and the lime converted from non-exchangeable form through natural weathering processes.

The available information on the loss of exchangeable CaO is very scanty. Apart from an important contribution by Crowther and Basu [1] on the Woburn experimental plots very little direct evidence can be obtained. Data from lysimeter experiments, drain-gauges, and crop-analysis indirectly give an indication of the losses likely to occur. Their application is, however, limited to soils of a similar character and under conditions similar to those from which the experimental data have been obtained. Even then, a complete picture of the changes in the lime-status of the surface-layer is not possible, as there is some release of calcium by weathering and from the decay of crop residues; also there may be some movement of calcium from layer to layer in the soil profile. An exact knowledge of the changes in the lime-status of soils can only be obtained from analysis of samples taken at the beginning and the end of a period sufficiently long to give significant differences.

Experimental

With a view to obtaining information of the kind indicated above, exchangeable-CaO determinations were carried out on, (1) samples collected from fields at the College Farm of the University College of North Wales in 1922 and in 1934, and (2) samples collected at intervals from farms in Anglesey. The mean annual rainfall at the College Farm is about 40 in., whilst that in Anglesey is slightly less.

The College Farm samples consist of borings from the surface-soil taken at intervals from an area having a radius of 15 to 20 yards. The position of these areas had been carefully noted at the time of the first sampling. Sampling errors are thus reduced to a minimum. The sampling errors of the Anglesey soils are likely to be greater, as they are representative of whole fields of varying sizes. As these samples were taken at intervals of 8 and 16 years, they will be considered separately from those of the College Farm.

College Farm soils.—Twenty-five samples were taken from six fields in different parts of the farm, representing both arable and pasture soils of varying lime-status and texture. In the short description given below, the letters refer to the field and the figures to the individual samples, of which not more than six were taken from any one field.

The College Farm is partly sloping and partly flat. The flat area includes all of fields I and L and the samples B 3 and D 2, 3, and 4. The remaining samples were taken from sloping ground. Soils B, J, M, and D 1, 5, and 6 are derived from Paleozoic shales and grits. They are stony, medium loams, and, as a rule, gravelly. Drainage conditions are good; although one or two samples, such as B 2 and B 3, show some signs of slight impedance these are comparatively insignificant.

Soil I forms part of the margin of a coarse alluvial fan and is a stony, shaly, medium loam with free drainage.

Soils D 3 and 4 and L 1, 3, and 4 are from a soil type characterized by a wash of local shaly material over boulder clay of Triassic origin. Although these soils overlie a stiff red clay, drainage conditions are as a rule fairly good. In texture they are medium to heavy loams. They contain far fewer stones and more exchangeable CaO than the other samples taken in this area.

Soil D 2 lies intermediate between D 3 and 4 and D 1, 5, and 6, but with definitely impeded drainage.

Soil L 5 is a medium to heavy loam derived mainly from local shales, and shows a somewhat impeded drainage.

Fields B, L, and M are old pastures and have received no manurial dressings during the period under investigation. The flat portion of field D (2, 3, and 4) has been under grass since 1921, and has received dressings of basic slag or mineral phosphates, representing an addition of about 0·012 per cent. of CaO. The remainder of the area, viz. fields D (1, 5, and 6), I and J, has been cultivated under rotation, and has received dressings of farmyard manure and other fertilizers during the period 1922–34.

The analytical results, given in Table 1, include figures for twenty-five soils from the College Farm, and show that, in all except three, the exchangeable calcium has fallen over the period under investigation, and that only in one soil, viz. D 2, has it appreciably increased. In view of this result fresh samples of the soil (D 2) were taken and analysed. The results agreed with those of the previous sample within 0·005 per cent. CaO. Thus the difference could not be accounted for by sampling errors. The explanation for this increase in exchangeable CaO is probably connected with the surface-relief of this field. It slopes down to a flat bottom which, at the foot of the slope, shows im-

TABLE 1. *Exchangeable Lime in, and pH values of, Soil Samples at the College Farm, Bangor*

Soil Number	Exchangeable CaO (per cent.) 1922	Exchangeable CaO (per cent.) 1934	Loss of exchangeable CaO (per cent.)	pH air-dry soil 1922	pH air-dry soil 1934
1A. *Old pasture soils*					
B 1	0·255	0·195	0·060	5·35	5·15
2	0·205	0·150	0·055	5·30	5·00
3	0·190	0·160	0·030	5·45	5·10
4	0·215	0·175	0·040	5·40	5·20
5	0·225	0·155	0·070	5·50	4·90
6	0·255	0·190	0·065	5·45	4·90
L 1	0·305	0·200	0·105	5·80	5·20
3	0·300	0·250	0·050	5·90	5·20
5	0·410	0·295	0·105	5·90	5·45
M 1	0·290	0·190	0·100	5·75	5·50
2	0·180	0·180	0·000	5·30	5·20
3	0·180	0·140	0·040	5·30	5·35
4	0·200	0·155	0·045	5·65	5·35
1B. *Arable soils*					
D 1	0·240	0·210	0·030	5·45	5·15
5	0·195	0·200	0·005*	5·50	5·30
6	0·230	0·205	0·025	5·50	5·25
I 1	0·225	0·175	0·050	5·70	5·05
2	0·235	0·155	0·080	5·70	5·00
3	0·175	0·140	0·035	5·15	4·90
J 1	0·355	0·275	0·080	6·10	5·50
2	0·390	0·315	0·075	6·15	5·75
3	0·395	0·305	0·090	6·10	5·65
1C. *Recent pasture*					
D 2	0·295	0·335	0·040*	5·80	5·90
3	0·460	0·360	0·100	5·85	5·60
4	0·380	0·315	0·065	5·90	5·90

Average fall in exchangeable CaO over a period of 12 years (per cent.)	All soils	0·054
	Arable soils	0·052
	Old pasture	0·058
Average fall in pH over 12 years		0·35

Figures marked * in column 4 are gains.

peded drainage. Further along the flat, where samples D 4 and D 3 are located (100 and 140 yards respectively from the foot of the slope), the drainage conditions are good. If the changes in exchangeable CaO figures are considered in relation to these circumstances, it is found that samples D 1 and D 6 from near the top of the slope show a distinct loss; sample D 5 from near the bottom of the slope shows a slight gain, whilst D 2 from the impeded drainage area shows a definite gain. Farther along the flat, where the drainage is again good, D 3 and D 4 show very distinct

losses. These results suggest some lateral movement of calcium from the upper to the lower levels, with an accumulation in the part of the field with impeded drainage.

If all the figures in Table 1 are averaged, it is found that the loss of exchangeable CaO for the 12-year period is 0·0538 per cent., or 0·0045 per cent. per annum. The loss from the old pastures is, perhaps contrary to expectation, slightly higher than that of the arable soils, being 0·058 per cent. CaO as against 0·052 per cent. Removal by crops and the effect of cultivation in facilitating drainage might be expected to result in increasing the loss of lime from the arable soils. That this does not follow is probably due to the additions, already referred to, of various mineral fertilizers and of farmyard manure. Those applied to the arable soils during the 12 years under consideration were as follows: 1 cwt. of sulphate of ammonia, 4–9 cwt. of superphosphate or basic slag, 5 cwt. of kainit or its equivalent of other potash salts, and 12–24 tons of farmyard manure per acre.

The exact effect of these fertilizers and manures on lime-status is difficult to assess. Crowther and Basu [1], in their investigations on the exchangeable bases of the Woburn plots, found that the losses of exchangeable calcium fell into the following descending order, according to manurial treatment: sulphate of ammonia: no manure: minerals (phosphates and potash): farmyard manure. Thus farmyard manure and minerals conserve the lime-status, whilst sulphate of ammonia increases the loss as compared with the no-manure plot. Unfortunately, they were unable to assess the separate effects of potash and phosphatic fertilizers; but they believe that 'for practical purposes it should be sufficient to regard superphosphate as without appreciable effect on soil reaction or lime-status'. This, however, may not be said of basic slag, for the writer [3] has shown that it conserves the lime-status by increasing the exchangeable calcium. Similarly, the position of farmyard manure in the above series may be attributed mainly to the calcium it contains, for analysis carried out by the writer on a dried sample of manure from the College Farm suggests that about 1 cwt. of exchangeable CaO is returned to the soil in every 12 tons of manure applied.

In view of these considerations, and of the fact that the dressings of sulphate of ammonia were small, it seems reasonable to conclude that the net effect of the above-mentioned added manures and fertilizers will be to conserve the lime-status. This is supported by the figures for the average loss from the arable and the old pasture soils. The arable soils have maintained their lime-status compared with the old pasture soils, despite the probably greater loss through drainage and removal in crops. As the difference is small, it may, for practical purposes, be assumed that the lime-status of the unmanured permanent pastures is reduced at about the same rate as that of cultivated soils receiving normal manurial dressings but no calcium carbonate or lime. Permanent pastures treated occasionally with basic slag would probably maintain their level better than cultivated soils. This suggestion is supported by the figures for some Anglesey soils discussed in the following section.

Anglesey soils.—A number of representative soils from Anglesey farms

were available for the purpose of this work. The information to be derived from the data for these soils was not expected to be as reliable as that from the College Farm soils for the following reasons: (1) The samples consisted of borings taken from whole fields varying in size from 4 to 16 acres; (2) it was not always possible to obtain information regarding manurial treatment; and (3) the soils varied in texture, cultural treatment, and drainage conditions. In general they are of a more open texture than the College Farm soils. It will be noted (see Table 2) that some of the soils have received heavy dressings of basic slag. The effect of the added calcium (1 ton of slag = 0·04 per cent. CaO) has been calculated by assuming that the slag contains 40 per cent. CaO and that an acre of soil weighs 1,000 tons. The values thus obtained have been added to the original exchangeable CaO (column 4).

TABLE 2. *Anglesey Soils*

			Exchangeable CaO (per cent.)		
Soil	*Interval (years)*	*Manurial dressing*	*Original + added CaO*	*After interval*	*Loss*
A 25	16	16 cwt. basic slag	0·280	0·255	0·025
A 30	16	No slag or lime	0·465	0·305	0·160
A 31	16	No information	0·150	0·145	0·005
A 44	16	,, ,,	0·540	0·395	0·145
A 72	8	,, ,,	0·280	0·215	0·065
A 74	8	1 ton basic slag	0·360	0·310	0·050
A 75	8	5 cwt. ,, ,,	0·190	0·160	0·030
A 78	8	5 cwt. ,, ,,	0·230	0·200	0·030

Average fall in exchangeable CaO per annum = 0·0053 per cent.

The figures in the above table show that the lime-status diminished over the period, and, as might be expected, the losses of CaO varied considerably. The two soils (A 25 and A 74) which received heavy dressings of basic slag are of interest, since without the allowance for the lime in the slag, A 25 would show an increase of 0·005 per cent. exchangeable CaO over the period of 12 years and A 74 a slight decrease of 0·008 per cent. over the period of 8 years. Thus the basic slag in these soils has maintained their lime-status at a fairly constant level.

The average annual loss of exchangeable CaO is similar to that for the College Farm soils, being slightly higher, 0·0053 per cent. compared with 0·0045 per cent. Thus the losses are of the same order for the two districts. As none of the soils examined contains free calcium carbonate, the foregoing evidence suggests that for non-calcareous soils under lowland conditions in North Wales the average reduction in exchangeable-CaO status is about 0·005 per cent. annually.

Factors affecting the Loss of Exchangeable Calcium

In the preceding section the average annual loss was shown to be about 0·005 per cent. This loss will be governed by three main factors: (*a*) the amount of exchangeable calcium present; (*b*) freedom of drainage; and (*c*) cropping.

(*a*) *Amount of exchangeable calcium present.*—That the amount of exchangeable CaO present influences the loss can be readily demonstrated and is shown graphically in Fig. 1, where the loss is plotted against the amount present at the beginning of the period. All the soils are included in this figure, the loss from the Anglesey soils being calculated on a 12-year basis.

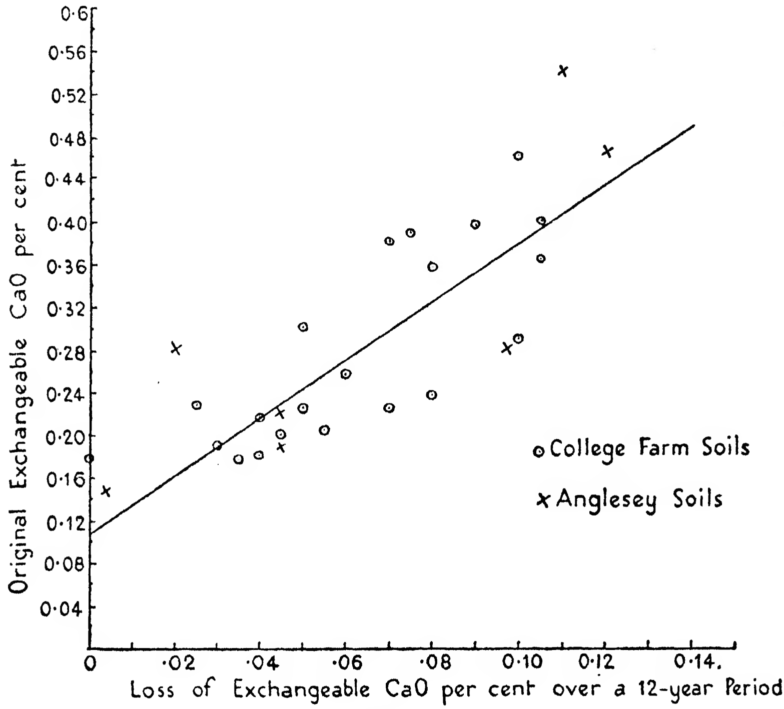

FIG. 1.

It is evident from the above diagram that there is a general tendency for the loss of lime to increase with the amount of exchangeable lime present. If the College Farm soils are divided into two groups depending upon whether their original exchangeable CaO was above or below the figure 0·25 per cent., it is found that the average loss of the higher lime-status group is about twice that of the lower lime-status group, being 0·084 per cent. as against 0·04 per cent. for the 12-year period.

It will be noticed that no soils of exchangeable CaO below 0·12 per cent. are included in this work. They are not common amongst ordinary cultivated lowland soils of normal organic content unless these soils are sandy. It may be that a state of equilibrium is approached somewhere about this figure, where the losses are balanced by the release of calcium through weathering processes. The general trend of the spot-diagram seems to suggest some such point for zero loss lying above zero exchangeable CaO.

(*b*) *Loss through drainage.*—The loss of exchangeable calcium from soils occurs principally through the drainage. For the College Farm

soils some information regarding this loss has been obtained from certain lysimeter experiments. Two lysimeters, 4 ft. square by 4 ft. deep, consist of water-tight tanks into which soil was placed in such a manner as to obtain, as nearly as possible, the natural soil profile. They were filled in 1925. From May 1929—when the soils had been given sufficient time to settle down—to May 1934, it has been possible to obtain figures for the amounts and concentration of the calcium passing through in the drainage. The soils were taken from one of the College Farm fields and originally contained 0·26–0·27 per cent. of exchangeable CaO in the top 12-inch layer. They have been cropped annually and during the above period each has received one dressing of farmyard manure and basic slag at the rate of 12 tons and 6 cwt. per acre respectively.

The total loss of CaO through drainage during the five-year period was:

Lysimeter A	414 lb. per acre
Lysimeter B	386 lb. per acre

This corresponds with an average loss of 80 lb. CaO per acre per annum, and an average content of 23·9 parts CaO per million in the drainage-water. The figures usually quoted in text-books from lysimeter and drainage experiments are much higher than the above, showing losses of from 140 to 330 lb. of CaO per acre per annum, with concentration of over 100 parts of CaO per million. Comparable figures are, however, obtained from the Aberdeen [2] experiments on the Craibstone soil, which is low in exchangeable CaO. The results are very similar, being 19·31 parts CaO per million and a loss of 76·1 lb. CaO per acre from the 'no-manure' plot over a period of 8 years.

(*c*) *Loss by cropping.*—It is somewhat difficult with the data available to assess the net loss from this source. As most of the crops are consumed on the farm a considerable amount of CaO will be returned to the soil in the farmyard manure. The CaO that is lost will be mainly in the form of milk and live stock sold from the farm. The amount lost in this way will be much less than that lost through drainage.

Discussion with Special Reference to Practical Applications

The figures presented give a reasonable indication of the changes likely to occur in lime-status of soils over a period of years under North Welsh conditions. Having regard to the relatively humid climate of this district, the losses are not as great as might have been anticipated. An increased loss would, however, be expected in those districts of North Wales where the annual rainfall is greater than that in the College Farm and the Anglesey areas.

Assuming that the top layer of the soil has an average weight of 1,000 tons per acre, the main results may be summarized as follows:

Average annual loss of exchangeable CaO per acre from all soils . .	106 lb.
Highest annual loss of exchangeable CaO per acre from any soil . .	224 lb.
Average annual loss of exchangeable CaO per acre from College Farm soils of original exchangeable CaO below 0·25 per cent.	75 lb.
Average annual loss of exchangeable CaO per acre from College Farm soils of original exchangeable CaO above 0·25 per cent.	157 lb.

In the earlier part of this paper it has been suggested that the lime-status of North Welsh soils should be maintained at not less than 0·25 per cent. exchangeable CaO. This generalization applies mainly to soils of medium texture. Soils rich in organic matter and heavy soils would probably need to be maintained at some higher level of exchangeable CaO, whilst sandy soils should be satisfactory at a slightly lower level.

From the data summarized above, it would seem that once a satisfactory level of lime-status has been reached, it can be maintained, under North Welsh conditions, by annual dressings of from 1½ to 2 cwt. of lime per acre. This result would of necessity be governed by the efficiency of the dressing in increasing the exchangeable CaO content. It is probable that, following a fairly heavy application, there will be a temporary increase in the rate of loss through leaching. Further, when lime is applied some of it becomes partially inactive through carbonation and caking, and only reacts with the soil very slowly. A 100 per cent. efficiency of the lime-dressing cannot, therefore, be assumed. The writer would recommend dressings at the rate of the highest annual loss, viz. 2 cwt. of lime per acre, in order to maintain the lime-status at the desired level in the soils of this area. In practice this addition of lime would be best accomplished by means of a heavy dressing once during the rotation. The average rotation-period under North Welsh conditions covers 7 or 8 years. Thus an application of about 15 cwt. of lime, or about 30 cwt. of ground limestone, per acre at some convenient time during the rotation would be required. Where the lime-status is below the minimum satisfactory level, a heavier initial dressing than this would, of course, be necessary. In regions of higher rainfall heavier dressings would be needed to maintain lime-status.

Summary

1. The percentage of exchangeable CaO has been determined on samples of surface-soil collected from North Welsh farms after intervals of 8, 12, or 16 years. These samples consist of two types, (*a*) borings from small areas having a radius of 15 to 20 yards, and (*b*) representative samples covering whole fields.

2. The results show an average annual loss of 0·00473 per cent. exchangeable CaO. The loss tends to decrease with the amount of exchangeable CaO originally present.

3. It is suggested that the exchangeable-CaO content of North Welsh soils, if already at a satisfactory level of lime-status, may be maintained by applications of lime or ground limestone once during the rotation at a rate equivalent to an annual dressing of 2 cwt. CaO per acre.

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AN EXPERIMENT ON OBSERVER'S BIAS IN THE SELECTION OF SHOOT-HEIGHTS

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Introduction

SAMPLING is now of common use in the study of agricultural problems. A recent paper by Yates [1] contains some discussion of the principles which must be followed if a truly representative sample is to be obtained, the most important of these being, to quote the author's own words, that 'the selection of the samples must be determined by some process uninfluenced by the qualities of the objects sampled and free from any element of choice on the part of the observer'. As an example of the biases which may arise in the sampling of agricultural material in cases where the observer's choice has influenced the selection of the sample, Yates quotes a case from the observations of the Crop-Weather scheme of the Ministry of Agriculture. Under this scheme, records are taken by sampling of the growth of the wheat-plant at ten stations. The sampling-unit consists of a quarter-metre of each of four consecutive rows and is marked off for observation by inserting a U-shaped rod, whose arms are parallel and a quarter of a metre apart, close to the ground and at right angles to the rows.

Measurements of shoot-height are made only on the two shoots nearest to each end of each row of a sampling-unit, so that there are eight measurements per sampling-unit. At one of the centres, only three rows were available for sampling, and in order to make up the full eight measurements the observer selected the two additional shoots 'at random' by eye. Comparison of the two additional observations with the six regular ones showed relatively large biases in the former. Of these Yates writes, 'On May 31, when the wheat was under 2 ft. high, there is apparently a simple tendency to select the taller shoots, with perhaps a special preference for the very tall shoots. On June 14, this tendency, though much less, is still noticeable, but there is now a tendency to avoid very high values. On June 28, when the wheat was about 4 ft. high, there is a marked avoidance of the tallest shoots, and also to a less extent of the shortest shoots. The general bias is now strongly negative.' And later, 'The biases are of course of the type that might be expected. When the shoots are low and there is nothing much to be seen except the top leaves, there will be a tendency to pick the higher shoots, but when they have come into ear the observer can see the shoots of all heights, and is more likely to select shoots somewhere near the average, omitting both very high and very low values. The strong negative biases of the last set of measurements show that this selection was not particularly effective in improving the accuracy of the sample.'

At a conference of the observers of the Crop-Weather Scheme, held at Rothamsted in June 1935, the opportunity was taken of carrying out an experiment to see to what extent these biases are common to all

observers who are making deliberate selection. The object of this note is to describe the experiment and its results.

For the experiment, six sampling-units were marked out, and the height of every shoot in each was measured. The observers were told to measure the height of two shoots in each row as usual, but instead of picking the end shoots, they were to select any two in the row which they pleased, so as to give what they considered to be a random sample of the shoot-heights in the sampling-units. There were twelve observers, who were divided into two groups of six. The members of the same group took their observations at the same time, but the order in which they made their selections from the various sampling-units was fixed by means of a 6×6 Latin-square arrangement, so that no two observers were measuring the same sampling-unit together. There were about 20 shoots per row within a sampling-unit, and the experiment was made about a week before ear-emergence, the wheat being 70 cm. high.

The Biases in Mean Height

The means of the 48 measurements on shoot-height for all the observers are shown in Table 1 below:

TABLE 1. *Observers' Estimates of Mean Shoot-height*

Group I		*Group II*	
Observer	*Height*	*Observer*	*Height*
	cm.		cm.
R. W. K.	76·79	R. M. H.	77·87
G. A. T.	76·31	A. J. G. B.	76·14
W. R.	76·87	F. H.	77·19
M. E. B. N.	77·62	A. J. M.	76·08
A. F. H.	73·42	B. J. T.	77·77
H. M.	71·96	I. Z.	72·77

True mean height = 70·75 cm.

In every case the estimate was higher than the true value and in all but three cases the bias was considerable, amounting to about 8 per cent.

The difference of each shoot-height selected by an observer from the mean height of the row in which the shoot lay was calculated. The mean differences per sampling-unit for the members of the first group are shown in Table 2:

TABLE 2. *Mean Differences in Shoot-heights*: Group I

Observer	*Sampling-unit* 1	2	3	4	5	6	*Total*
R. W. K.	$+5\cdot88^{6}$	$+7\cdot18^{5}$	$+6\cdot68^{1}$	$+4\cdot48^{2}$	$+5\cdot10^{4}$	$+6\cdot95^{3}$	+36·27
G. A. T.	$+8\cdot88^{2}$	$+4\cdot18^{1}$	$+4\cdot55^{4}$	$+3\cdot72^{3}$	$+3\cdot48^{5}$	$+8\cdot58^{6}$	+33·39
W. R.	$+9\cdot62^{3}$	$+10\cdot18^{4}$	$+4\cdot05^{5}$	$+2\cdot98^{6}$	$+4\cdot10^{1}$	$+5\cdot82^{2}$	+36·75
M. E. B. N.	$+10\cdot50^{4}$	$+7\cdot55^{6}$	$+5\cdot82^{2}$	$+6\cdot60^{1}$	$+5\cdot98^{3}$	$+4\cdot95^{5}$	+41·40
A. F. H.	$+3\cdot12^{5}$	$+3\cdot68^{3}$	$-0\cdot70^{6}$	$+3\cdot72^{4}$	$+2\cdot36^{2}$	$+3\cdot82^{1}$	+16·00
H. M.	$+3\cdot50^{1}$	$+1\cdot92^{2}$	$-2\cdot70^{3}$	$-3\cdot28^{5}$	$+3\cdot98^{6}$	$+3\cdot82^{4}$	+7·24
Mean	+6·92	+5·78	+2·95	+3·04	+4·17	+5·66	

The small figures indicate the order of the observations.

Time Means

Time:	1	2	3	4	5	6
Mean:	+4·81	+4·88	+4·54	+6·31	+3·25	+4·71

There appear to be fairly large differences in the biases from observer to observer and from sampling-unit to sampling-unit. This is brought out by the analysis of variance on mean differences, which is shown below for the members of Group I. The analysis for Group II is in all respects similar.

Analysis of variance: mean differences per sampling-unit

	Degrees of freedom	*Sum of squares*	*Mean square*
Observers	5	154·4	30·87
Times	5	28·54	5·71
Sampling-units:			
Regression on mean shoot-height	1	59·91	59·91
Deviations from regression	4	18·66	4·66
Remainder	20	66·61	3·22
Error			
Random sampling variation	288	1,684·44	5·85

It will be noticed that the 20 degrees of freedom which remain after removing the sums of squares due to observers, times, sampling-units, and the mean have been called 'remainder' and not 'error'. The reason for this is that although these 20 degrees of freedom contain a component representing the sampling variation of the observers, which is the true error, they are also influenced by interactions between observers and sampling-units and between observers and times, if these exist. Thus if the difference in bias between observers were much greater in some sampling-units than in others, this would inflate the 'remainder'. In the absence of anything better, the 'remainder' would have been used as error, but as it happens, we can get a proper estimate of the sampling variation of observers from the differences of the two samples taken per row. This is shown in the last line of the table and has 288 degrees of freedom. It will be seen that the 'remainder' mean square is actually lower than the error mean square, so that the interactions mentioned above appear to be negligible.

Comparing the mean squares of the various items with the error mean square, we see that the differences in the sizes of the biases of different observers are significant. This is quite to be expected from previous experience. The size of the bias was not, however, affected by the order in which the sampling-units were measured, for time-effects are not significant, nor is there any sign in the times-means given in Table 2 of a regular change in the bias from the first sampling-unit measured to the last.

The size of the bias varies significantly from sampling-unit to sampling-unit, and the question arises, to what is this due? In the example by

Yates quoted above, it was shown that the bias in selection was correlated with the true mean shoot-height, being positive when the shoots were low and negative when they were high. A comparison of the mean biases per sampling-unit with the true mean shoot-heights (shown in Table 3) indicates that a similar relation is present here also.

TABLE 3. *Mean Biases and Mean Shoot-heights*

Sampling-unit	*Mean bias*		*True mean Shoot-height*
	Group I	*Group II*	
1	6·92	8·12	59·0
2	5·78	7·63	66·2
3	2·95	2·59	76·4
4	3·04	5·14	74·5
5	4·17	4·45	76·0
6	5·16	5·20	72·3

In the analysis of variance, the linear regression of the mean differences on the true mean shoot-height was taken out. The regression is highly significant, and the mean square of the deviations from the regression line is slightly below the error mean square. The variation between sampling-units, apart from that due to error, may thus be accounted for by the linear regression of the bias on mean shoot-height. The positive bias in the height of a shoot increases by about 0·2 cm. for each cm. decrease in the true shoot-height. This provides a striking illustration of the errors to which human judgement may be subject.

The Distribution of the Sampled Shoots

The distributions of the differences of the heights of the sampled shoots and of all shoots from the means of the rows in which they lay are shown on the same scale by the unshaded and shaded portions respectively of the histogram in Fig. 1. The positive bias already referred to in the sampled observations is clearly shown. A striking feature of the comparison is the much smaller variability in the differences of the sampled shoots, the sampled shoot-heights being much more closely grouped about the mean. Shoots which were smaller than the mean by more than 20 cm. are scarcely represented at all in the samples. This confirms the result found in previous investigations that observers, when given freedom of choice, select samples which conform much too closely to the average, even when they are instructed to make their samples representative of all the material which is being sampled.

The distributions of the differences of the sampled shoot-heights were calculated separately for the centre and outside rows, to see whether the easier accessibility of the two outside rows made any difference to the type of sample which was taken. The results are shown below in Table 4, the two distributions together forming that represented in the unshaded histogram in Fig. 1.

There is no marked difference between the two distributions. That from the outside rows shows, however, a slightly greater variability, hav-

ing rather more observations in the two extreme groups at either end of the scale. The fraction of observations in these four groups was not, however, significantly higher for the outside rows.

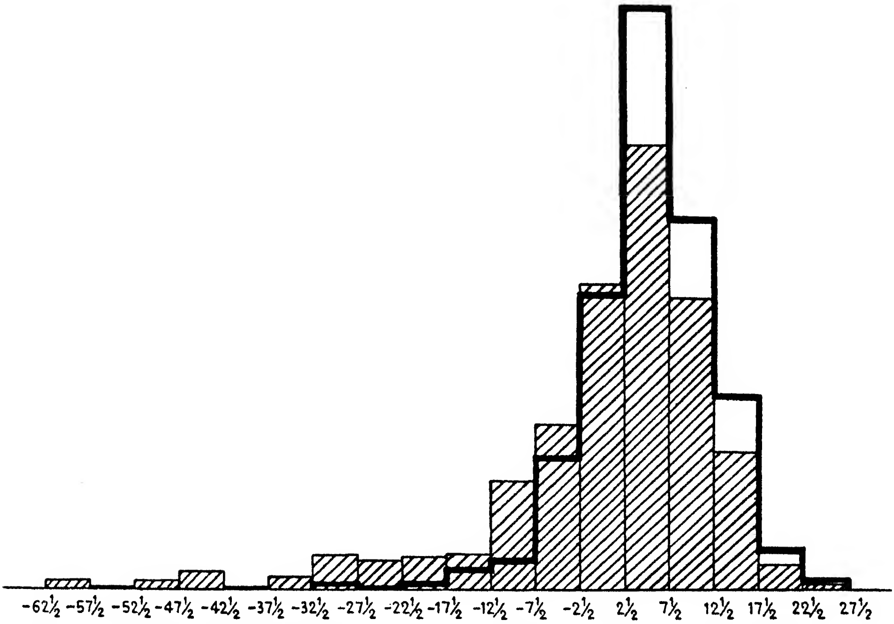

FIG. 1. Distribution of sampled shoots (unshaded) and of all shoots (shaded).

It has already been pointed out that the observers' samples showed a much smaller amount of variation than the population from which they were sampling. A more detailed examination was made of the variation in the observers' samples. For each observer there are eight differences per sampling-unit and an estimate of the variation between these may be made by taking the sum of the squares of the deviations

TABLE 4. *Distribution of the Observers' Differences in Centre and Outside Rows*

Group	−32½−27½	−27½−22½	−22½−17½	−17½−12½	−12½−7½	−7½−2½
Number of observations:						
Centre	0	0	2	5	3	25
Outside	2	0	0	2	7	20

Group	−2½+2½	+2½+7½	+7½+12½	+12½+17½	+17½+22½	+22½+27½	*Total*
Number of observations:							
Centre	43	110	60	35	5	0	288
Outside	58	89	67	31	9	3	288

of these differences from the mean differences and dividing by seven. An analysis of variance was performed on these estimates of variance in the same way as that already described on mean differences. In both groups of observers the differences in variability between different observers were significant. The variability did not, however, differ

significantly, or indeed at all abnormally, from sampling-unit to sampling-unit or from time to time. The observers' estimates of the variability within a sampling-unit lay between 16·0 and 93·4. The correct value from the whole set of shoots was 187·6. Thus even the best of the observers in this respect estimated the variance at less than half its true value, whereas the worst obtained only about a twelfth of the true value. It is worth noting that the three observers who made the best estimates of mean shoot-height were amongst those who made the best estimates of the variability.

The Validity of the Sampling Process actually Used

The sampling process actually used consists, as mentioned above, in taking the two shoots nearest to the ends of the rows. The location within the sampling-unit of the shoots which are measured is certainly free from any element of choice on the part of the observer. The eight shoots which are measured do, however, always occupy the same positions within the sampling-unit, and it is of interest to see whether in this case they formed a representative sample of the shoot-heights in the six sampling-units. One reason on general grounds for doubting this is that with a patchy growth the outside shoots of a plant have a greater chance of being selected than the inner shoots, owing to the presence of a blank space in the row next to the plant. In the present case the growth was fairly even.

We may examine the heights of the 48 end shoots in the same way as the observers' samples were examined, and consider whether the former give an unbiased estimate of the true mean shoot-height and a reasonably good representation of the distribution of shoot-heights.

The mean of the 48 end shoot-heights was 71·375 cm., the true mean being 70·75 cm. The difference is $+0·625$ cm., its standard error, calculated from the 48 deviations, being $\pm 1·987$ cm. The difference is well within its standard error, so that there is no sign of bias in the estimate of mean shoot-height.

The distributions of the differences of the end shoots and of all shoots from the row means are shown by the unshaded and shaded histograms in Fig. 2. The unshaded histogram shows no sign of abnormality and could reasonably be regarded as a random sample from the whole distribution. In particular, the estimate from the end shoots of the variance with a sampling-unit, calculated in the same way as for the observers' samples, comes to 174·4, which agrees well with the true value of 187·6.

The evidence of this experiment thus provides no reason to doubt the validity of the sampling process which is being used for shoot-heights in the Wheat Sampling Observations.

Conclusions

It is obvious that samples that are picked by a process of randomization which gives every sample in the population an equal chance of being picked, must be representative of the population from which they

are drawn and give an unbiased estimate of the quantity which it is desired to measure. Those who have little experience of the technique of sampling might, however, be unwilling to admit that they could not do as well, or better, by choosing the samples themselves. In this experiment, out of twelve observers, all of whom have had some train-

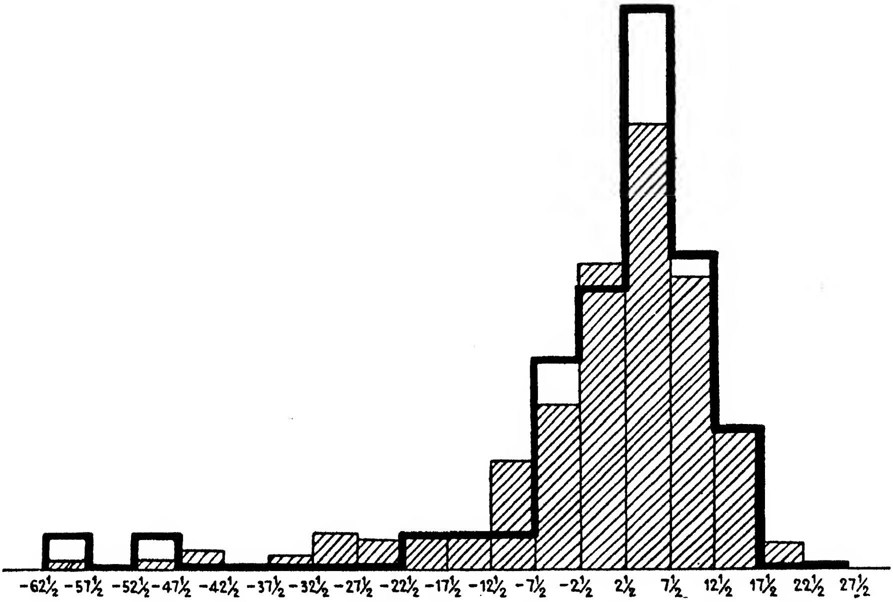

FIG. 2. Distribution of end shoots (unshaded) and of all shoots (shaded).

ing in sampling, not one managed to pick a sample that could be called representative of the material from which they were sampling, and all except three obtained relatively large biases in their estimate of the quantity, mean shoot-height, which was being measured. Further, the biases, both in mean shoot-height and sampling variance, showed large differences from observer to observer. What is even more serious and striking is that the individual observers were not consistent throughout the experiment; the positive bias in selection increased regularly as the mean height of the sampling-unit decreased.

This experiment, in short, very strongly supports the evidence from other investigations that the only sure method of avoiding bias is for the sampling to be random. The plea has sometimes been made that observer's bias is not important provided that the same observer does all the sampling. The answer to that in the present case is that there is no excuse for bias at all in such a simple problem as the estimation of the shoot-height of a field. In many sampling problems, however, particularly in sampling from bulk, it is much more difficult or troublesome to obtain a proper random sample, and for this reason the plea merits some investigation.

In the first place the plea is based on the assumption that the observer's bias remains constant. Neither the present example nor the one discussed

by Yates supports this view; in both, the positive bias in the estimate of mean shoot-height decreased regularly as the true mean height increased. Thus the observer's estimates of differences between the mean shoot-heights of different varieties in the field would be biased. The true mean shoot-heights on this date (June 17) and the observer's estimates are shown below for two of the varieties grown at Rothamsted:

Variety	*True values* cm.	*Observer's estimates* cm.
Victor	70·7	75·8
Yeoman	63·7	70·5
Difference	7·0	5·3

Victor was the variety used in the experiment. The observer's estimate for Yeoman was calculated from the regression of observers' bias on true mean shoot-height obtained above. The true difference in height, 7·0 cm., would have been under-estimated by 24 per cent. A similar case occurs in the example discussed by Yates [1], in which the growth-rate would have been under-estimated by 9 per cent.

Even granting that an observer might have a constant bias, the uses to which his results can be put are very limited. A constant bias would give a correct estimate of differences, but almost all other estimates based on his figures, such as for example percentage differences or regression coefficients, would be biased in different ways. No one can foresee, when making observations, all the estimates or comparisons which may be made from them at some future date. Further, the comparison of one observer's work with that of another will be vitiated by the fact that they will have different personal biases; and this difficulty is almost certain to arise in any work carried on at more than one place, or for any length of time at the same place. In short, the presence of observers' bias in sampling results greatly detracts from the value of the results, and one of the most important problems in the application of statistical methods to agriculture and industry is to devise reasonably quick methods of taking a proper random sample in cases where the material sampled is difficult to demarcate or handle.

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THE DEVELOPMENT OF NATIVE AGRICULTURE IN THE NUBA MOUNTAINS AREA OF KORDOFAN PROVINCE, ANGLO-EGYPTIAN SUDAN

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THE Nuba Mountains area is approximately 150 miles square and lies between Lat. 10·18° and 12·15° N. and Long. 29·00° and 31·3° E. It consists of several fairly well-defined ranges of rocky hills and numerous isolated outcrops of granite. Extensive and comparatively level valleys surround the hills.

The pursuit of agriculture in this region depends entirely on the rainfall, which, presumably due to the presence of the hills, is, taking the area as a whole, consistent, and usually well distributed throughout the wet season. Practically all the rain falls between early June and the middle of October. Local variations in the total annual rainfall may run from 25 to 40 in., as heavy storms are often local in their incidence, but, generally speaking, one expects to get an annual rainfall of more than 30 in. over most of the area. The soil is very variable, ranging from clay or heavy loam in the valleys to what is almost gravel close to the hills.

The inhabitants can be divided into two main groups, Nubas and Arabs. The former are a negroid race, the latter are mostly rather dark-skinned for Arabs and in this country are known as *Baggara*, which means 'cattle-owning'.

Had it not been for the mountains, the Nubas would probably have been overrun by the Arabs in the old slave-trading days. As it was, they were able to defend themselves in their mountain fastnesses and to retain their racial characteristics. They were able to grow most of their food-requirements on terraces on the hill-sides. There is an adequate water-supply, either on, or close to the foot of, most of the mountains. It will be seen, therefore, that, in times of danger, there was very little necessity for the Nuba to leave his mountain stronghold. His wants from the outside world were few; he wore no clothes, his cooking utensils were made of local pottery, and his houses were made of stone, mud, grass, and branches cut from trees, of which there is a plentiful supply both on the hills and on the plain.

Evidence of fortifications can still be seen on some of the hills. They generally took the form of rough stone walls built across the narrow valleys or gorges which gave access to the mountain mass. In some cases the Nuba did not rely on one line of defence only, but built two or even three walls one behind the other.

This comparative isolation has had its effect on the Nuba; though of a naturally genial nature, he is shy of strangers and of people whom he does not know well. This makes it essential for any one, who wishes to introduce him to new crops or to new (to him) methods of farming, to get to know him and to be known by him. This task is made more difficult by the fact that several different languages are spoken by different

sections of the race and many dialects of these languages are in common use. It is no uncommon thing to find the Nubas living on two hills only 10–20 miles distant from one another speaking different languages.

Another effect that isolation has had on the Nuba is that it has made him independent. From time immemorial he has had to rely on himself for all his wants. These being few, and the chief of them being food, the result is that, judged by African standards, he is a good cultivator and a steady worker. Any one making a journey through the Nuba Mountains in the early part of the year, after all the grass on the hill-sides has been burnt, cannot fail to be amazed at the enormous amount of work which must have been needed in the past to complete the vast amount of terracing which is then easily seen.

Up to the present little has been said about the Arab section of the population. It is probably true to say that most of the Arabs found in the Nuba Mountains were originally Baggara. Many of them are, however, not true Baggara to-day. The true Baggara depends for his livelihood almost entirely on his cattle; during the wet season he moves his herds north out of the Nuba Mountains area, and gradually moves south again after the rains, when grass and water become scarce in the north. Many of the Arabs now found in the Nuba Mountains, though originally true Baggara, have lost their herds through one cause or another, and have become sedentary, depending on their crops for their livelihood.

In 1899, when the present Sudan Government came into being, conditions in the Nuba Mountains were very unsettled. The Nuba still kept to himself and was difficult to approach for administrative purposes; communications were bad; Nubas and Arabs were always quarrelling, and even one section of Nubas was always liable to fight another section.

As time went on conditions began to improve. Both Nubas and Arabs were made to realize that there was now a Government whose orders had to be respected.

About twelve years ago the Government had made considerable progress in the administration of this area, but even then considerable sums of money had to be spent almost annually on the employment of troops to aid the administration in enforcing its orders, and in keeping peace between the various sections of the inhabitants.

At this stage the Government decided that the least expensive method of procedure would be to try to increase the interest of the inhabitants in agriculture; in other words, to 'turn their swords into ploughshares'.

In this connexion the introduction of a cash crop appeared to be the solution. It was considered that American-type cotton would grow well under the conditions prevalent in that area, and cotton at that time was fetching very high prices on the world's markets.

The Government at first endeavoured to interest private enterprise in this proposed development of cotton-growing. However, their efforts in this direction failed, and it was finally decided that the Government must initiate cotton-growing itself, and that it must be prepared to carry on the industry for some considerable time.

It fell to the lot of the writer to be sent to the Nuba Mountains in 1924 to start cotton-growing and to organize the new industry from the start.

In eleven years the output of cotton has risen from nothing to over 400,000 kantars of seed-cotton, a kantar being approximately 100 lb. Expressed in bales of American cotton (480 lb. net), this means 25,000 bales, which at 6*d*. per lb. at Port Sudan means a cash crop worth £300,000, of which slightly less than half goes to the grower, the remainder being used up to pay the cost of ginning, transport, &c. Seven ginning factories have been erected by Government in this area, and two more will be completed shortly. Most of the cotton grown is sold under marks N.M.K. or N.M.T., and it usually averages nearly 1*d*. per lb. in value over standard American.

Eleven years ago the chief crops grown in the Nuba Mountains consisted of dura (*Sorghum vulgare*), simsim (*Sesamum indicum*), and ground-nuts (*Arachis hypogaea*). Since then, as already mentioned, cotton has been added. This has been effected partly, but by no means entirely, at the expense of the other crops.

The native system of farming, which has been in force from time immemorial, has hardly been changed at all up to the present. It consists of a partial clearance of the land (the larger trees only have their branches lopped off) and then the growing of crops for three or more years running. After this the cultivator moves on and clears another area, leaving his old plot to recover its fertility under natural conditions. He may or may not move back to it after the lapse of some years, but when he does the operation of clearing is nearly as heavy as it was in the first instance.

The use of ploughs, or indeed of any animal-drawn implement or cart, was unknown until very recently. Even now the Nuba section of the inhabitants has no idea of the use of animals, even for pack-transport purposes. The Arabs, on the other hand, have always used their bulls for riding and for pack-transport.

The Government started two or three demonstration farms seven or eight years ago. On these the use of animal-drawn implements and carts has been shown, and a few cultivators are now copying the example given them.

The tools in general use by cultivators are distinctly crude and consist of several different forms of what we should call a hoe, or, in the case of the cruder forms, a spud. On the heavier land all the hoeing is done by a man squatting down and pushing a short-handled spud in front of him.

Under the present system of native agriculture, land is never under cultivation long enough to become really clear of weeds and grass, consequently the amount of hoeing which is necessary to produce a good crop is always heavy. On the demonstration farms it has been shown that where land is kept under continual cultivation by means of a rotation of crops, the amount of hoeing necessary is very materially reduced after a few years.

It was realized from the first that the introduction of a cash crop like cotton was only the first step in the agricultural development of this area. It was nevertheless a very necessary one, as without money very little can be achieved. Progress has been so rapid that it is now possible,

and even urgently necessary, to introduce the next step. This is the adoption of rotations coupled with the use of animal-drawn implements. At the present time cultivators have become so bitten by the desire to make money by cotton-growing that they are tending to neglect their food crops. It is hoped to introduce a rotation whereby only one-third of the land under cultivation each year is under cotton, the remaining two-thirds being half under grain and half under a leguminous crop or, alternatively, simsim. The question whether a fallow is really necessary to keep up the fertility of the soil has not been definitely decided yet.

The general effects of such agricultural development as has taken place up to the present, beyond the important fact that the local sword is indeed fast being turned into a ploughshare, are as follows:

(*a*) The Government has been able to administer the area much more closely. What were, until recently, scattered semi-independent units of the same, or closely allied, tribe, are now being welded together under a comparatively small number of native administrations. This in itself will materially aid further agricultural development. It will be readily understood that agricultural propaganda is likely to be far more successful if it is passed on to the cultivator through his own native administration, rather than directly by agricultural officers. This is especially true of Nubas, among whom the agricultural officer is always up against the language difficulty referred to above.

(*b*) The Government has been able to provide greater medical and educational facilities, and also to improve communications. I might almost say 'to provide communications', as eleven years ago there were practically none.

(*c*) It has been possible to cut down military garrisons, and consequently to save expenditure.

(*d*) Trade has improved because cultivators have money to spend.

(*e*) The collection of taxes is now comparatively easy.

Up to the present, agricultural development has not affected the local native agricultural systems or methods of cultivation to any very great extent. There is certainly far more land under cultivation than there used to be, and a valuable cash crop has been successfully introduced. Cultivators can also obtain small supplies of improved seed of various crops other than cotton from the demonstration farms. Cotton-seed is issued by the Government free to cultivators, and no other cotton-seed than this may be sown.

After a further eleven years of agricultural development it is hoped that there will be a very different tale to tell. A start has already been made to try to introduce the use of rotations, and of animals for cultivation. Every assistance is being given to chiefs to run small farms on the accepted principles of what we may call mixed farming. It is hoped that after the cultivators have seen the effects of farming in this way for a few years, they will adopt the new (to them) method without much further persuasion.

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SOME EFFECTS OF THE DEVELOPMENT OF THE COTTON INDUSTRY ON NATIVE AGRICULTURE IN UGANDA

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THE effects of the cotton industry upon the Uganda native and his agriculture have been so great that it appears best to treat the subject by comparing pre-War with present conditions: the period 1914–18, when the cotton industry was still comparatively small, marks a convenient transition period.

Before the War the primary and practically the sole object of all native cultivation in Uganda was to obtain food for the population. In this matter every village, and, indeed, almost every household was a self-contained unit; transport of agricultural produce from district to district hardly existed, and there were no large centres of population dependent upon outside communities for their food-supplies. Under such conditions land was cultivated merely to ensure an adequate food-supply; the population was distributed in small groups of huts scattered through the general bush and grassland, each group having its small patches of food-crops. As the land around the huts became unprofitable for cultivation, the natives either opened new fields from the bush, or abandoned the site and moved elsewhere. With the limited areas necessary to support each unit of population there was then no lack of 'virgin' land to act as a reserve. The population and the herds of cattle were kept in check to some extent by inter-village and inter-tribal disputes; the cattle were also controlled by epidemics of rinderpest and other diseases.

These conditions, which had probably prevailed for centuries, together with the very limited amount of agriculture, had practically no effect upon the fertility of the land as a whole. In the more thickly populated areas of Buganda and Busoga a very advanced type of agriculture was practised; the primary food-crop was the banana, supplemented by sweet potatoes, ground-nuts, and various beans. It was the duty of the women of each household to cultivate the banana plantations and to ensure a regular and sufficient supply of fruit. The men did comparatively little, except to clear the land for new plantations; for the rest, the man's duties were those of a warrior and protector. A very efficient method of agriculture was evolved; the banana plantations were carefully tended, and the soil was covered with a mulch of weeds, and waste leaves and fibre from the bananas. All early travellers in Uganda were greatly impressed by this high standard of agriculture. With the careful cultivation and mulching practised, the soil deteriorated but little through erosion and exposure to the sun, and the banana plantations could be considered as permanent. Occasional replanting was necessary, owing to the old stools of the bananas gradually becoming raised above the general ground-level.

In the drier parts of the country the main food of the natives was 'bulo' (*Eleusine coracana*). This is an annual crop, taking some five or six months from sowing to harvest, and often two crops per year were

sown, though not on the same patches of land. Ground-nuts and various beans were sown on the old bulo fields to supplement the diet; for the rest, large herds of cattle were kept. Apparently there was a regular rotation of the bulo fields, each of which was cultivated for one or two years, and then allowed to revert to grass and bush for some five or six years. The only permanent clearings were the hut sites and cattle kraals. In spite of the lighter soil of these areas as compared with that of the banana areas of Buganda and Busoga, little erosion of the soil could take place during the short periods of cultivation. The bulo fields were small and surrounded by grassland which acted as a barrier to serious erosion.

In all areas cultivation was entirely by hand, various forms of hoe being used; in some areas the actual tillage amounted to little more than the removal of the natural grasses and a surface-scratching of the soil. As a rule deeper cultivation was employed in Buganda, where an indigenous grass, 'lumbugu' (*Digitaria abyssinica*), is a menace to all agriculture, and unless this is controlled very poor results are obtained.

The history of the development of the cotton industry has been dealt with elsewhere;[1] it suffices to say that at present about a million acres of this crop are cultivated every year in Uganda. A large proportion of this area represents an increase in the cultivated area, and this increase has reacted upon the native and upon his general outlook on life.

Apart from propaganda and general advance in education of the native, the growth of the industry has been assisted by economic and other pressure upon the population. Many cases still occur of natives regarding their cotton crop as the chief means to enable them to pay their taxes in cash; and once the seasonal taxes have been paid, these individuals have little interest in the crop. It has been estimated that some 15 per cent. of the 1934–5 cotton crop in Lango was burnt by the native growers at the end of the season, when the plants were uprooted; having paid their taxes for the year, they did not feel inclined to pick the remainder of their crop merely to increase their cash income. In the future such cases will disappear, as the native is realizing more and more the benefits he can obtain from the possession of money.

Hitherto, in the stages of rapid extension of the industry, all possible attention was concentrated upon getting the natives to grow the crop, and to extend their acreage year by year. We have now reached the stage at which most of the natives are familiar with the crop, and with some of the advantages to be gained from growing it; we are now faced with the more difficult problem of improving the standards of cultivation and thus increasing the yield per acre. To some extent the more intelligent and ambitious natives are working to this end, but in many areas little or nothing is being done. Much propaganda and education will be required to obtain satisfactory results throughout Uganda. In many areas it has proved an almost hopeless task to induce the natives to re-sow blank holes in their cotton plots; and progress in this matter is not assisted by the attitude of some chiefs, whose sole concern is to return as large as possible an acreage under cotton, and who care little about the

[1] See the Annual Reports of the Uganda Dept. of Agriculture; also various papers in the *Empire Cotton-Growing Review*.

condition of plots already sown. The result is that much of the acreage planted has to be discounted as unproductive, and the average yield per acre is lower than it need be. The variety trials conducted by the Agricultural Department at some ten or eleven centres in the Eastern Province usually show a large increase in yield over that of the native cotton around them, in some cases double or treble; this is probably the result of careful filling of blanks and better cultivation. It would be more economical to fill blanks in the early sowings than to expend labour upon later sowings, even if these were slightly reduced in acreage, as in any case the later sowings do not give as high a yield as early sowings. Continuation of the present system of acreage-expansion is likely to prove disadvantageous in the future, in so far as it means less care of the plots planted early in the season. The raising of the average yield per acre is likely to achieve better results in the future than further large extensions of acreage under cotton. In encouraging the native to take better care of his plots, we have either to combat his natural apathy or to utilize it by showing him that, for the same cash return, less labour is required to grow one acre of good cotton than two acres of rather poor cotton.

In the 'banana areas' of Buganda and Busoga most of the cotton is grown separate from the banana fields, and the two cultivations of bananas for food and cotton for cash bear little relation to each other. New land may be opened for cotton and later planted to bananas, but the latter are a permanent crop. Almost all native cultivation in Buganda is still carried out by hand, but in Busoga ploughing has considerably extended of late, and the area under cotton has much increased. It is still too early to assess the advantages or disadvantages of this development, as we have little experience of the effects of ploughing and of more frequent cultivation of land in Busoga, which is quite different from the land in Teso and Bugwere, where large-scale ploughing was developed earlier.

Of late there has been a marked deterioration in the general standard of banana cultivation in Buganda, to which many factors have contributed, one of the most important being the gradual emancipation of the women from their previous condition of virtual slavery on the land with little or no compensating labour on the part of the men. The cotton crop has enabled each family to enjoy a regular source of income in cash, much of which is spent on clothes and bicycles, and consequently the natives are no longer tied down to their own holdings or villages, but can travel to inspect and sample the amenities of the larger towns and trading centres. The banana cultivations have therefore received rather less attention, especially as the women accompany their menfolk on their travels, or even travel without them. Exceptions are found chiefly in the outlying areas, or in plantations belonging to the older generation, who are naturally more conservative. The lower standard of banana cultivation now practised is largely responsible for the recent increase of the banana weevil (*Cosmopolites sordidus*), which has become quite a serious pest in some areas, and further reduces the yield of food per acre.

In Buganda, owing to the development of cotton production, the

cultivated area has extended at the expense of the forests and grasslands on the slopes of the hills. Hence soil-erosion has become a problem, and the natives must now be taught to take all possible precautions to prevent it. In the more densely populated areas the reserves of land are now comparatively small, and conservation of the fertility of the present cultivation is all the more important. With good standards of cultivation the banana food-supply of the population should remain assured indefinitely, but there has been a decided tendency to lower the old standards, and even to replace the banana by sweet potatoes, with consequent increased danger of soil-erosion. Every effort should be made to induce the native to return to his old intensive cultivation of bananas, and thus to control the weevil borer. Such a policy would lead to an improvement in the cultivation of other crops, including cotton.

Many of the Baganda are ambitious to become landowners, so that in the future they may settle on individual holdings and develop an inclination to conserve the fertility of their own land sooner than less settled tribes. At the present time there is room for improvement in the attitude of the large landowners and chiefs to this question. The former, in particular, appear to regard their estates purely as a source of revenue from rents, and few concern themselves with the standard of agriculture practised by their tenants. As these large estates become split up on the death of their owners, there is hope that in the future the owners will be forced to cultivate their holdings themselves, as these will be too small to support them as landlords. In this way the pressure of economic necessity is likely to help in raising the general level of agriculture in these areas.

Unfortunately there are now large areas in Buganda where the production of cattle manure is very limited; but with improved control of cattle diseases and pests the herds may be expected to increase and then mixed farming is likely also to increase. It is improbable that the dangers of over-stocking and over-grazing will occur in Buganda for some years to come.

The 'bulo areas' of Teso, Lango, and Bugwere are areas of comparatively light soil, and have a long dry season from November to March. At other times they are liable to very heavy falls of rain, often more than an inch falling in an hour; between these heavy rainstorms are periods of one to three weeks of hot dry weather. If the soil is bare during the heavy storms, serious erosion may occur even on very gentle slopes; in any case much of the water runs off the surface and is lost for agricultural purposes. The result is that these areas, even under natural conditions of bush land, look very dry as compared with Buganda and Busoga, where the soil is heavier and the rainfall more evenly distributed. The elephant grass (*Pennisetum purpureum*) characteristic of the latter districts does not occur to any great extent in Teso or in most parts of Lango and Bugwere.

In these 'bulo areas' the cotton crop has been included by the natives in rotations with their annual food crops. A common rotation in Teso is for fresh land to be opened in April and May for planting to cotton some five or six weeks later. The cotton is followed by bulo, sown in January

or February, as soon as there is enough moisture in the soil to permit germination; and the bulo crop is followed by a second crop of cotton, sown immediately after the bulo harvest in June–July. After the second cotton crop is finished the land may be sown with ground-nuts, simsim (*Sesamum indicum*), beans, or sweet potatoes; alternatively it may be abandoned. Many plots are cultivated for at most three years, after which the land is allowed to revert to grass and small bush for some five or six years before it is again cultivated. The result is that even in centres of fairly dense population there always appears to be a large reserve of land uncultivated, which is utilized for grazing the large cattle herds. Under primitive conditions the cultivated area of each village was restricted to that necessary for food-production, and, owing to the long periods of rest under grass and bush then possible, the effect of cropping the land was practically negligible; but with every extension of the area cultivated, the periods of rest are shortened. Also, since these areas have been ploughed, individual plots have been enlarged and soil-erosion has correspondingly increased, especially where the furrows left by the plough do not conform to the contours of the land. Cattle numbers have increased side by side with the development of cotton and the better administration of the country; the natural control by inter-village strife and by epidemics of disease has been removed to a large degree. All these factors have resulted in increased demands on the soil for crop-production and for grazing during the intervals between cultivation periods; in some areas the soil is evidently deteriorating.

An additional factor has recently become more pronounced than in the past, namely, the increased tendency of the native to 'clean clear' his cultivated land. Under the old conditions, even if this were practised, very little effect was produced on the country as a whole, on account of the small areas so cleared, but as the cultivated area has extended the effect of this practice upon the general aspect of the country has become more marked; in Kumi county of Teso district the land is now practically denuded of trees and bush. The more intensive grazing now occurring aids this process by retarding the natural regeneration of the bush flora. The area mentioned is now somewhat deficient in water-supply, but it is difficult to determine to what extent this is a direct result of the clearing of the bush.

In the dry season the whole of the grass covering the land is burnt off. This practice appears to have been general for many years, but it is conceivable that under bush conditions the effect was less dangerous than it is in areas now under prairie, where the bare soil is exposed to hot dry winds and sun, and at the beginning of the rainy season is liable to heavy erosion. Kumi county may be an extreme example of the processes at work, but there are other areas in which the early stages are now becoming visible. The native population is tending to migrate from Kumi into areas close by, and if this continues we may expect the prairie area to encroach upon them in the near future. The development of cotton-cultivation must be held responsible for much of this change, though other factors have also assisted. At the moment it appears, therefore, that in the areas of lighter soils there are grave dangers attendant upon

the extension of the cotton and cattle industries. In these areas it has become very important to develop a system of agriculture that will conserve the natural fertility of the soil, or even increase it; and in areas like Kumi to evolve a method of regeneration before the processes at work have gone too far.

At first sight the obvious solution is to settle natives on individually-owned holdings of a more or less permanent nature, and thus give them a direct interest in the improvement of their land. Large herds of cattle are available for use in a system of mixed farming. One of the great obstacles in the way of this solution is that the whole idea of individual ownership of land is foreign to the natives of these districts (Teso, Lango, and Bugwere). It may be possible to adapt the idea of mixed farming to small communities, using each village as a unit, rather than individual households. Under present conditions such adaptation is likely to progress more quickly than settlement of these tribes on individual holdings.

In any case, before progress can be made the native must be convinced beyond doubt that it will pay him well to abandon his present ideas. He must first be shown the superior value of a permanent holding on which mixed farming is pursued, as compared with his present system of shifting cultivation. Attempts in this direction are now being made by the Agricultural Department, and many small holdings have already been established. It is still far too early to say if success has been achieved, and the systems of cultivation and crop-rotation now being used on them may need considerable revision later in the light of further experience or future changes in economic conditions. It is probable that in any case some adaptation of the present system of shifting cultivation, or rotation of cultivation-periods with grazing-periods, will be necessary on these holdings; in fact, those at Serere are already being run on such a system.

These demonstration holdings will have to prove very successful indeed to overcome the natural prejudices of a primitive agricultural people, and until they have done so it is useless to expect the population as a whole to follow the example set them. On the holdings mixed farming is practised, the manure from the cattle kraals being used on the areas set apart for the various crops each year in regular rotation. There is some evidence that in bygone days the Teso did make some use of the manure from their kraals, but they do not do so now. Much propaganda is needed at the moment to impress upon every native the value of this manure, and to demonstrate the profit to be obtained from the labour expended in carting it to the fields. One great drawback is that wheeled transport is not available to the native, but he can with little expense make crude sledges to transport the manure.

Green manuring has been suggested as a possible means of improving present conditions, but apart from the fact that it is likely to prove impossible to induce the native to expend his labour on a crop merely to dig it into the soil again, the results obtained on Serere Plantation in the past indicate that under the special conditions of these districts this form of manuring is of doubtful advantage, as it entails extra cultivation of the soil and consequent loss by erosion.

Although the old method of hand-cultivation has certain advantages

over ploughing, it is obvious to any observer that the latter has come to stay, and is rapidly extending into all districts. By means of it the native is able to bring more land into cultivation with less labour. It therefore remains for us to devise methods of cultivation by plough best suited to local conditions; investigation is required into the best type of plough, the best time to plough the land, the optimum depth of ploughing, &c. It is still possible that a type of plough which leaves the soil in a state more comparable with that produced by hand-hoeing might prove better than the present mould-board type, which inverts the soil and also tends to form a plough sole on some types of soil.

We are still ignorant of the effect of heavy grazing on the local flora and soil, but it should be possible to obtain data on this point from the demonstration holdings mentioned above, provided the cattle on them are kept within the holdings and not allowed to roam, as they are now. At present it is impossible to obtain any accurate data on the area per head of cattle needed for grazing throughout the year, and this lack of information becomes important in the designing of demonstration holdings; the grazing area allotted at present is a mere guess.

Control of the clean clearing of cultivated areas is admittedly necessary, and steps are being taken to stop the natives ringing and burning the larger trees they encounter when opening new fields. Afforestation of the badly denuded areas, such as Kumi, presents difficulties. If trees are planted on a large scale, the question arises as to the best position for the plantings: on the tops of the ridges or in the swamps. An area sufficient for the food and cotton requirements of the natives must be reserved for cultivation, as well as sufficient for grazing their cattle. From the health point of view it would be preferable to plant the swamps, but this leads to dessication through improved drainage, and at present these swamps supply water for the population and the cattle. From the standpoint of soil-conservation and prevention of erosion, it would be better to plant the tops of the ridges, and to limit the cultivation areas to the gentle slopes, where precautions must be taken to prevent erosion by surface-water.

The main problem in the further development of cotton production and of native food production in Uganda is to increase yields rather than to extend the cultivated area. Such increase can be obtained partly by producing improved varieties of cotton and of native food-crops, and partly by introducing improved methods of agriculture, notably mixed farming. The settling either of individuals or of small communities on permanent holdings is likely to lead to progress, but is certain to be very slow and gradual, especially in the Eastern and Northern Provinces. It is possible that in some areas the native now obtains just as good results from his present method of shifting cultivation as he would if settled on a permanent holding. In the future, however, it is probable that the results from the present system will fall off, especially in areas of fairly dense population; for after the area available has all been cultivated once, the periods of rest from cultivation are certain to become progressively shorter. At the moment we need to obtain all possible data on intensive cultivation of small areas of land, on a system of mixed farming and manuring with cattle manure, the grazing of the cattle being also limited

to definite areas. If possible we should set the natives an example by means of demonstration holdings.

Past experience on government plantations has shown that, provided soil-erosion can be controlled—a very difficult matter—it is possible to cultivate the land almost indefinitely by the use of fairly heavy applications of cattle manure. The erosion under cotton is far above that under other native crops, and attempts should be made to control it. Some degree of control can be obtained by interplanting cotton with ground-nuts, with the additional advantage of reducing the cultivation area for the same total production and expenditure of labour. Recent experiments indicate that this interplanting is possible under some conditions, and that the ground-nuts have little effect upon the yield of the cotton; the actual cash return per acre is also larger.

On the other hand, with the supplies of cattle manure available, it is likely to prove impossible to cultivate continuously an area sufficient to support the population, as yields fall off after a few years. Some system of resting the land under grass must be included; but the present native system involves the use of too large an area per head of population, and we have to design a system whereby the cultivation-period of each plot can be extended, while at the same time the final residual fertility is kept at a maximum, so that the rest-period can be shortened. Experiments are in progress on the Indore method of producing compost and various modifications of it, with the object of providing a larger supply of rich manure; the chief drawback is the amount of labour required to transport the requisite large quantities of grass and water. There appears to be little hope for many years to come that the native will adopt this means of increasing his supply of manure.

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THE INTRODUCTION OF MIXED FARMING IN NORTHERN NIGERIA

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In the general experience of Colonial agricultural departments it has been comparatively easy to induce native farmers to grow a new and profitable export crop or improved varieties of such crops, but it has been by no means so easy to induce them to alter their general agricultural methods. This is not because the native farmer is inherently conservative; indeed, he seems generally to be less conservative than the European farmer. The difficulty arises from the fact that, among primitive people, agricultural methods are very intimately bound up with tribal traditions, with land tenure, and with the economics of village life. Thus it often happens that what appears to the European mind to be a comparatively small change in agricultural practice involves consequences which, to the native mind, appear most formidable. There is also the further difficulty that most of the fundamental improvements which the European agriculturist can suggest to the native farmer necessitate the investment of a certain amount of capital. Judged by our standards, the sum required may be very small, but even £5 is far more than the average native peasant in Nigeria can produce.

During the last year or two the introduction in Northern Nigeria of a system of mixed farming *cum* animal husbandry has progressed at a rate that is already remarkable, and that continues to increase every year. This new system represents an improvement of the first magnitude, and involves a revolutionary change in the farmer's whole outlook upon his life and business. It may therefore be of interest to discuss the difficulties we have encountered and the methods by which we have overcome them.

In countries where there are both European and native farmers, experience has shown that the Europeans' example has influenced the improvement of the native farming. But there are no European farmers in Northern Nigeria (the cotton-seed farm belonging to the Empire Cotton-Growing Corporation is the only exception to this statement), so that the only agency through which the new system could be introduced was the Agricultural Department of the Nigerian Government, working in close co-operation with the various Native Administrations. The Government has, therefore, had to provide for the necessary research and field-experimental work, to devise a means of getting into direct touch with individual farmers, and to provide loans to enable the farmers to meet the initial outlay on cattle and implements.

An account of the climate of Northern Nigeria and the existing agricultural methods has been given by the authors elsewhere.[1] For the purpose of this article it is sufficient to mention that, before the introduction of mixed farming, all cultivation was carried out by hand, and various types of hand-hoe were the only agricultural implements used.

[1] *West African Agriculture*, by O. T. Faulkner and J. R. Mackie.

There were some three million head of cattle (of the Zebu type) in the country, but these were kept almost entirely under nomadic conditions by Fulani herdsmen, who did practically no cultivation. The cultivator as a rule owned no cattle, though he appreciated the value of their manure, and obtained it by paying Fulani herdsmen to 'kraal' (herd) their cattle on his fields at night during the dry season. It must be admitted that, wasteful as this system is, it achieved amazing results, as is shown by the annual export from Nigeria of some 200,000 tons of ground-nuts and some 20,000 tons of cotton, in addition to the production of all the corn and other foodstuffs for the whole population. In thickly populated areas, such as those surrounding the big towns, the land was maintained in permanent cultivation at a high level of fertility by frequent manuring. Elsewhere a much lower level was maintained by a combination of manuring and shifting cultivation.

When the Agricultural Department began its investigations it seemed fairly clear that a really important and great improvement would be effected if, by some means or other, animal husbandry and cultivation could be combined. There seemed scope for the introduction of animal-drawn implements; for more intensive crop production by the better conservation of manure; and also for the increased production of milk. It was realized from the outset that the introduction of ploughing alone would be a retrogressive rather than a progressive step: for by providing for the cultivation of an increased area, ploughing, by itself, would aggravate, rather than alleviate, the problem of shifting cultivation. It was clear, therefore, that the provision of a much greater supply of manure must go hand-in-hand with the introduction of ploughing. Further, it was necessary to provide suitable implements, the cost of which would be within the means of the peasant farmer; and also to find out whether the local cattle could be trained for farm work, and whether, when trained, they would stand up to such work. It was evident, too, that any improvement of the local cattle, whether for milk, work, or beef, depended on providing them with adequate food during the dry season, and that this condition could only be satisfied if the cattle were kept on their owners' farms, instead of being collected into large herds and sent off in the charge of Fulani herdsmen. The question of feeding during the dry season was therefore another problem which had to be faced.

The previous history of ploughing with cattle in Nigeria was not encouraging, for several previous attempts to introduce it, including one made by the Agricultural Department itself, had all failed. These previous attempts emphasized the necessity for preliminary experimental work. The main reason for the failure of one attempt was the use of a type of plough which was quite unsuitable for the country. Another attempt had failed because the cattle suffered too much from Trypanosomiasis; and a third because the cultural methods used were not suited to the local climate. At the outset, therefore, of our renewed effort, the agricultural officers, plant-breeders, and chemists were constituted into a team of experimenters with instructions to investigate every aspect of the subject. Their objective was to evolve a system of which every detail had been tested and re-tested in field trials and experiments. Subse-

quent events have proved the wisdom of this procedure; and it is also found that the greater the progress we make in our extension work, the more important the experimental work becomes. For now that we have gained the confidence of the farmers, we can less than ever afford to give any advice, by precept or example, which is not based on accurate and certain knowledge.

The preliminary experimental work occupied some six years, and during this period no attempt was made to induce even one native farmer to adopt our methods. The results of the main experiments are given in the Annual Bulletins of the Department, and they show that every detail which could possibly have any important bearing on the problem was fully investigated. At the end of this period we had reached the stage of having evolved a suitable cheap wooden plough, and had satisfied ourselves that the cattle were suitable for work, were easily trained, and would stand up to work. We had also carried out many experiments to ascertain the best method of making and utilizing manure, and we were satisfied that the manure from one pair of working animals, properly conserved and applied, would serve to keep some 10 acres of land at a reasonable level of fertility. It was not a very high level, but it was one which is very much higher than that of the ordinary hand-hoed farms, even of those that receive occasional 'kraaling' by Fulani herds. As soon as it seemed certain that the system was thoroughly practical and sound, we made an effort to induce three farmers to give it a trial; so that we might next learn whether our system, which seemed so sound to us, could really be adopted by an ordinary farmer, or whether it would need modification before it could be acceptable to him. During this time the Veterinary Department had perfected its system of immunizing cattle against rinderpest. This work has contributed largely to the success of mixed farming; without it we should have been in the position of asking farmers to invest their money in cattle, with the knowledge that they were almost certain, sooner or later, to lose them from that disease.

We realized at a very early stage that very few farmers, if any, could provide the capital to purchase the cattle and implements, and to stump their land sufficiently well to enable the implements to be successfully used. So, before serious extension work could be started, it was necessary to devise a scheme by which the farmer could obtain a loan at a moderate rate of interest and repayable over a period of years. To overcome this difficulty very small sums, sufficient for a few men only, were provided by the Native Administrations as an experiment. This small experiment has since been developed, and loans are now offered by the Native Administrations to any approved applicant who wishes to start mixed farming. The Native Administration organization is also used as the medium through which both capital and interest are repaid; and although the number of loans issued each year has steadily increased, until the total amount of money involved is now considerable, the system works satisfactorily and instalments are repaid with commendable regularity. The success of the system depends upon keeping the loans as small as possible, in order that they can be easily repaid in 3 or 4 years. Every

effort is therefore made to keep each loan down to a sum not exceeding £5. This sum provides a pair of working bullocks, a locally made plough, and a simple cultivator. Under the system which has been adopted, the loan, together with interest, is repaid in four instalments; and the farmer also pays 5*s*. in cash before he receives his cattle and implements. The arrangement is illustrated by the table given below:

	Capital repayment	*Interest*	*Total*
	£ *s*. *d*.	*s*. *d*.	£ *s*. *d*.
Cash	5 0	About 4 9	About 1 4 9
At the end of the 1st year	15 0		
At the end of the 2nd year	1 5 0	„ 4 0	„ 1 9 0
At the end of the 3rd year	1 10 0	„ 2 3	„ 1 12 3
At the end of the 4th year	1 5 0	„ 1 3	„ 1 6 3
	£5 0 0	„ 12 3	„ £5 12 3

The Native Administrations, in order to assist the scheme, have set aside the money they receive as interest to form an insurance fund, which can be drawn upon to replace unavoidable losses of cattle. Minor difficulties have occurred from time to time, and various adjustments have been necessary; but the system is proving to be a sound investment for the Native Administrations, and it is not unlikely that the provision of advances will become one of their permanent functions. Already the system is being extended to include the purchase of cows and of imported ploughs by those farmers who have repaid their initial loans. It cannot be too strongly stressed that in countries like Nigeria, where peasant agriculture predominates, the provision of these small loans at a reasonable rate of interest is essential to any considerable advance in agricultural methods. The working of such a scheme of loans necessitates the very close co-operation of administrative officers; and they should be regarded, and should regard themselves, as an essential part of the team of workers by whom the improvement is to be effected.

The first three farmers met with varied degrees of success, and one failed entirely; but the experience gained with these men enabled us to rectify one or two minor weaknesses of the system which we had worked out; and it also convinced us that, given a suitable method of getting into touch with them, our system would be adopted by many farmers.

Up to this stage, our work had been mainly confined to our few big experimental farms. These farms are of necessity run on European lines. The very nature of the experimental work entails the presence of several European officers, the laying out of the farms in plots and straight rows, clean weeding, full stands of plants, and so on. Experience has shown that the ordinary farmer is not much influenced by what he sees on such farms. He merely regards them as the farms of the Europeans, tends to avoid them, and takes little interest in the work that is being done on them. The big, highly organized experimental farm is therefore of very limited value as a medium for introducing improved methods in such a country as Nigeria.

In order to get into closer touch with the farmer it seemed essential that we should make every effort to work through his own Native Administration, and that we should try to demonstrate our system as nearly as possible under his own conditions. This object has been achieved by a system of farm centres and demonstration farms, financed and staffed by the Native Administrations under the advice and supervision of Agricultural Officers. This system has proved so successful in enabling us to get into touch with the individual farmer that we have adopted it as the basis of all our extension work.

The essential feature of the demonstration farm is that it shall resemble a native farm as closely as possible, and that it shall be operated by a labourer working and living under the same conditions as the local farmers. Our demonstration farms each consist of from 10 to 15 acres, which we have found to be the maximum area that can be well cultivated and manured by one ordinary farmer owning a pair of bullocks and possibly a cow and some small stock. The buildings consist of merely a house for the labourer and a pen for the cattle, both built of exactly the same materials and in the same style as the houses of the local farmers. The labourer is a man who has been trained by us, but who is, if possible, a local man; and provided that he farms well, on the lines laid down by the Department, he is given a free hand and receives a minimum of supervision from European officers. We have found that it is best to pay the labourer a definite wage and to sell all the saleable produce available from the farm. An alternative system by which the labourer receives no wage, or a very small one, but receives the produce, was tried but proved unsatisfactory. Under that arrangement we had not sufficient control of the working of the farm. For a man working on that system cannot, in fairness, be removed in the middle of the cropping season. Yet it is essential that every detail of the system should be properly demonstrated, for it is attention to every detail that ensures success. Thus it is important that the cattle should receive sufficient bedding, that all waste products of the farm should be conserved, and that the implements should be used to the fullest extent. In such matters the unpaid labourer is apt to be slack; the paid labourer can be kept up to the mark or be replaced by another.

Only practices which have been proved by experiment to be absolutely sound in every way are demonstrated on the demonstration farms, no experiments of any sort are carried out on them; but the system demonstrated does not remain entirely stable from year to year, for every advance in our knowledge, as obtained from our experiments, is incorporated at once in the system which is demonstrated on these farms. All farmers have free access to the demonstration farms and are encouraged to visit them as often as possible. They can receive instruction and advice from the labourer in charge, and can also send their boys to the farms for practical instruction in the use of implements or the management of cattle.

The farm centre differs only from the demonstration farm in that it is on a bigger scale and provision is made for carrying out minor experiments under local conditions. For example, if the Botanist obtains an

improved strain of cotton on the main experimental farm, it is again tested at the farm centres before being given out to the demonstration farms. This is an important function of the farm centres, for Northern Nigeria is a vast area comprising a wide diversity of climatic and soil conditions, and the number of main experimental farms which the Government can afford to maintain is, owing to their cost, obviously limited. Yet it is unlikely that improved strains or methods evolved at one or two places will be suitable for the whole of the Northern Provinces. The farm centres give opportunity for tests in many localities; they, like the demonstration farms, are also increasingly used as training centres for both boys and cattle; sick cattle are brought to them for treatment; and there is also a blacksmith's shop where implements are made and repaired. Both farm centres and demonstration farms are cheap to establish and to maintain, and every effort is made to ensure that, as a result of good farming, they are self-supporting, i.e. that the cost of working them is offset by the value of the crops produced.

The value or otherwise of small demonstration farms is a point which has often been debated by officers of agricultural departments, and opinions about this subject have differed widely. The conclusion which we have reached in Northern Nigeria is that such farms are an invaluable method of disseminating results to individual farmers. Demonstration farms are, however, only a success if they are really necessary, that is, if there is something of value to demonstrate which cannot be demonstrated otherwise. Such a farm will not be a success if its object is vaguely to demonstrate general good farming, nor if it merely introduces a new variety of seed, which could just as well be demonstrated on farmers' own fields. Our experience has shown that the farms are essential for the introduction of such a system as that of mixed farming, and as we are only just at the beginning of the problems connected with animal husbandry in Northern Nigeria, it is probable that we shall have something of real value to demonstrate for many years to come. If we ever reach the stage when we have nothing new and important to demonstrate, then the demonstration farms will be closed down; for when that stage is reached the farmers who have already adopted our system successfully will provide a better demonstration than anything we could provide.

Up to the present we have had to concentrate our main efforts on getting farmers started; for the purchase and training of the bullocks, and the manufacture of the implements in sufficient numbers are tasks of some magnitude. During the present season some 300 applicants were 'set up', and probably twice that number will be started next year. The necessary organization for dealing with much greater numbers is gradually being evolved.

The ordinary farmer normally cultivates only about 3 or 4 acres, and he cannot clean and stump some 6 or 7 extra acres all at once. He does so gradually, and it takes him about three years to increase the size of his farm and obtain the maximum production from it. In the meantime he learns the value of providing his cattle with an adequate supply of bedding in order to obtain the maximum quantity of manure; he learns also that his cattle must be well fed, and how to provide the food most

economically; he also learns that they must receive prompt attention as soon as they show the very first signs of ill health. The next step is to induce him to keep a cow, for the produce of one good cow will bring him in a greater net income than 2 or 3 acres of land when produce prices are at a normal level. Several farmers have already obtained cows, and the demand increases every year. As milk is such a valuable commodity it was clearly worth while to make an attempt to improve the performance of the local cows, and a stock farm for the improvement of cows was an obvious corollary to the introduction of mixed farming.

The improvement of live stock cannot be achieved quickly: it takes several years from the commencement of such a scheme to the time when the improved animals can be placed in the hands of the ordinary farmer. This was realized by the Nigerian Government at a very early stage, and a stock farm was established very soon after the experimental work on mixed farming was begun. Consequently, by the time when a considerable demand for improved cows will arise, we hope to be in a position to supply them, at least in limited numbers; and also to have bulls of heavy-milking strains available in adequate numbers, so that every farmer shall be able to take his cows to an improved bull.

Our work at the stock farm is confined to an attempt to improve the local cattle by selective breeding, and we have resisted the temptation to try to achieve quick results by introducing improved breeds from other countries. There are several well-defined types of cattle in Nigeria and we are at present working on four of them. Under the nomadic conditions in which the cattle are normally kept by the Fulani herdsmen, very little improvement is possible; but even under such conditions there are some strains with inherent milking-quality. When these animals are kept on the farm and are well fed throughout the year their milk-yield improves immediately. Selective breeding in itself therefore offers no serious difficulties, and progress in this direction has been more rapid than might have been anticipated. The main problem connected with this work has been that of feeding. We were quickly able to demonstrate that if a farmer conserves all the waste products of his farm, such as the leaves of his guinea-corn crop, his guinea-corn bran, and the leaves and stems of his ground-nut crop, he will have an adequate supply of food for his working beasts; but the provision of a suitable ration for high-yielding cows throughout the long dry season was a much more difficult problem. Although we are not yet satisfied that everything possible has been tried, we have been able to work out a suitable ration of foodstuffs grown on the farm that meets our present needs. This ration is based on using a leguminous crop for hay and sweet potatoes as a succulent fodder crop. Both roots and vines of this crop are readily eaten by the cattle and are most nutritious, and the yield per acre is very satisfactory. The farmer will naturally not wish to devote more of his land to the growing of fodder crops than is absolutely necessary, so we are still trying to find more quickly growing and heavier-yielding fodder crops than those which we have at present.

The introduction of mixed farming on the lines indicated above is a revolutionary change in native agricultural methods, and its full effects

on the country cannot yet be foreseen. Many problems still remain to be solved; but the progress made up to the present is most encouraging. A means has been found by which the results of research and experiments can be brought to the notice of every farmer, and it is certain that both specialist officers and agricultural officers have a programme of useful work before them which will keep them fully occupied for a period of many years.

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NATIVE PRODUCTION OF COFFEE ON KILIMANJARO

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WITH PLATES 7, 8

History of Coffee in Tanganyika Territory.—Wild coffee is indigenous to Tanganyika Territory, the varieties *C. arabica* h. var. *Stuhlmannii* Warb (= *C. bukobensis* Zimmerii = *C. robusta* L. Linden), *C. arabica* h. var. *intermedia* Fraehner (this also is very probably *C. robusta*), being found in the region of Lake Victoria Nyanza; *C. zanguebarica* along the coast; *C. Schumanniana* W. Busse in the Rovuma valley on the southern border of the territory, and *C. mufindiensis* Hutch. M.S. in the southern highlands.

Coffea robusta has been grown for many generations by natives in the Bukoba district on the west shore of Lake Victoria Nyanza; its cultivation is mentioned by the early explorers Speke and Grant, and some of the existing trees are reputed to be over 100 years old. It is only in comparatively recent times, however, that the crop has been cultivated for export on an extensive scale; formerly the bean was used solely for chewing. *Coffea arabica* is also cultivated in Bukoba, whence it was introduced by missionaries about the year 1896. To-day the exports of native-grown coffee from Bukoba amount to about 7,000 tons of the *robusta* type and 3,500 tons of *arabica*. In this area the coffee is prepared by the Brazilian method of drying the whole cherry, and the native separates the bean by hand-hulling and winnowing. The coffee is regarded as a low-grade type, equivalent to Brazils, but, possibly owing to bulk-marketing at the port of export and grading, the prices obtained have not fallen in proportion to the fall sustained by the higher-grade mild coffees, prepared by the more skilful wet method of pulping and fermenting.

In the northern part of the territory, on the slopes of Mount Kilimanjaro, *arabica* coffee was introduced by Father Auguste, of the Kilema Mission. The seed was obtained from Réunion (Bourbon) and was first planted in 1883 near Morogoro (the present head-quarters of the Department of Agriculture), but after several years it was cut out owing to the high incidence of *Anthores*, the white stem-borer. In 1893, seed from these trees was planted at Kilema on the southern slopes of Kilimanjaro; some of the trees of this planting are still bearing well. (In 1896 or 1897, seed was taken from Kilema to the Bura and Nairobi localities of Kenya Colony.) The crop soon established itself on Kilimanjaro, where it was cultivated by the missions, their native followers, and by the early European settlers. In 1899 coffee to the value of £4,817 was produced, and in 1934 the production of European and native-grown coffee on the mountain amounted to 1,361 and 1,530 tons, respectively; in 1935 it is estimated that the production of native coffee on Kilimanjaro will amount to 2,000 tons. The coffee is prepared by the wet method of pulping and fermentation and is well regarded as a good-quality mild coffee on the London market.

There are other coffee areas at Arusha, Babati, and Oldeani in the Northern Province, and in the southern highlands; in these areas production is mainly European, but natives are taking an increasing interest in the crop. It is, however, with coffee grown by natives of the Chagga tribe on Kilimanjaro that this article is mainly concerned, especially in regard to the influence which the European has had in the development and improvement of native agricultural practice in regard to coffee.

Coffee on Kilimanjaro.—The coffee-belt of Kilimanjaro lies between the altitudes of 3,000 and 5,500 ft., the most favourable areas being on the southern slopes. Coffee also extends to the western and eastern slopes, and decreases towards the northern slopes, which are without permanent water and are uninhabited. The rainfall varies between 35 in. at the lower levels to 80 in. and more at the upper limits of coffee-cultivation. There is abundant water, which is used by the Wachagga for irrigating their food crops, and by both natives and Europeans for irrigating coffee. Although, generally speaking, the estates owned by Europeans are confined to the lower and medium elevations, with the majority of the native holdings above them, there is no definite line of demarcation, and some estates are practically surrounded by plots of native-owned coffee.

Thus we have a position where a cash crop is successfully grown by native and European agriculturalists without segregation, and, whilst there is no doubt that the initial example set by the European has been a dominant factor in establishing the valuable native coffee industry, it is not correct to hold, as some do, that the cultivation of coffee on Kilimanjaro was actually initiated by the European settler. As stated above, missionary enterprise first demonstrated that coffee was a suitable crop, and, although few in number, natives were the first to follow their lead. It was, however, the European planter who first exploited the economic possibilities of this crop, and it was not until 1902 that natives began to see its commercial possibilities. White influence of the benevolent kind was seen, for the headmen of the early settlers were encouraged by their employers to grow coffee: seed was given out to natives, notably by an Italian, de Croce, and by Dr. Forster, a German. The German Government also appears to have given some encouragement, since native growers of wheat, European potatoes, and coffee were exempt from certain forms of communal labour.

The influence of missions was also extended in the direction of preaching industriousness to the people, particularly to the menfolk, whose activities in the agricultural sphere prior to coffee-growing must have been much less than to-day. In former years the European grower relied chiefly on the local native tribe for his labour-supply and the habit of working, and a sense of orderliness, which is essential to coffee culture, was instilled into many Wachagga during their employment on coffee estates. The comparative affluence of the European, especially during the times of high prices, was attributed by the natives to coffee, and an ever-increasing number imitated their employers' example and grew coffee for sale. A result of this was that, as with sisal, it became necessary to recruit labour in such districts as Songea, and again the

effect is that to-day many natives from the Matengo highlands of Songea, before undertaking recruitment, stipulate that they shall be employed on coffee estates, with a view to being coffee-growers on their own account. The influence of the planter in extending the cultivation of a staple product is thus seen to be potent, and spreads far beyond the confines of the locality in which he lives. In 1916 the number of native-owned coffee-trees is given as 14,000 only, and in 1922 the total was 125,000. Natives knew of the high prices obtained for coffee at that time, and there was a rapid increase in their plantings. One of the earlier growers started a nursery for the supply of seedlings to his fellow tribesmen, and planting material was readily offered by, and purchased from, European coffee-growers. At this time the influence of Government became predominant, and Major Dundas, the administrative officer in charge of the Moshi District, did much to encourage coffee-growing by natives on Kilimanjaro.

Thus we see the establishment of a now important native coffee industry by the efforts of missionaries and by the early benevolent influence of planters. The prosperity of the European coffee-grower during the period 1920–28 was a considerable incentive to native coffee-growing, and from 1922 Government took an increasing interest in the industry and supplied white supervision: the latter influence was, and remains, most important.

The political aspect.—With the rapid extension of coffee-growing by natives in the past decade, the European producer feared that native plantings would be a source of pest- and disease-infection, and would be a menace to his own crop in which much capital was invested. Opposition to native coffee-growing became vocal, and this, strangely enough, further energized native plantings. It is generally and historically true that there is no object more desirable than that which is forbidden, and when the Wachagga realized that the European settler would at least like to restrict their coffee crop, they became all the more determined to have and to hold it. In the face of such opposition, the temper of the native coffee-planters in the early years of the technical supervision given to the crop was such that they came to regard their coffee jealously as a precious possession; almost every European who had anything to do with the crop was regarded with suspicion, and strenuous objections were always advanced against the uprooting of any native coffee under the Plant Pest and Disease Regulations, as they suspected such action to be the thin end of the wedge to eliminate all native coffee. Consequently the work of the Agricultural Officer was difficult, and it became more or less police work.

At the same time certain leaders were wise enough to realize that there was truth in the European allegations. To counter these, they set about forming the Kilimanjaro Native Planters' Association for the purchase of spray-equipment and chemicals for communal use. The effectiveness of spraying had been amply demonstrated to them on European plantations, and natives would work on such estates merely to obtain knowledge of pest- and disease-control, as well as of pruning and coffee culture generally. The leaders of the Association also adopted the tactics of

complaining of the state of certain European coffee estates whenever propaganda against their own plantings was advanced. The critical attitude of the white planters thus went far towards causing the natives to endeavour, for their own protection, to put their house in order. The extent of such influence was seen a year or two ago when an article was published in a local paper containing serious adverse statements about native coffee; the effect of this was that the leading natives of the area concerned convened meetings of growers. It was admitted that there was a certain amount of truth in the description given of their coffee, and a time limit was set by their leaders for all offenders to place their coffee in a satisfactory state. A rapid clean-up was effected. There is no doubt that the criticisms to which the native coffee-grower has been subject over the past decade have given an impetus to the industry and have assisted in raising the standard of coffee culture.

The spread of European practice.—In addition to the knowledge gained from the European planter concerning the methods of pest- and disease-control, the native has learnt to give careful attention to the production of seedlings in the nursery, to planting out in orderly fashion, and to pruning. In fact, pruning, as well as irrigation, until fairly recently was rather overdone by the European, and the fault has also occurred with much native coffee. Such careful culture is not seen in Bukoba, where there are only a few European planters, and where the coffee has been allowed to grow, often to advantage, in a comparatively uncared-for condition.

Again, in the preparation of the coffee-bean, in Bukoba, partly because of water shortage but mainly because it is the line of least resistance, the cherry is dried and a low-grade coffee is produced, whereas on Kilimanjaro the native has followed the European idea of pulping the fresh coffee-fruits and fermenting the seeds to remove the mucilaginous matter from the parchment covering the bean. At one time there were a number of locally made wooden pulpers in use, but, following the more efficient use of up-to-date equipment by the European coffee-grower, these have been almost entirely replaced with imported metal pulpers of the breast type. Approximately one coffee-grower in ten has one of these modern pulpers, and those who have not make arrangements for the use of one at a rental based on the amount of the cherry which is pulped. Following this operation, each grower ferments and washes his own coffee in wooden boxes, or occasionally, following the European idea, in cement tanks. The parchment coffee is then dried on wire trays, when some hand-picking of defective beans is carried out.

Native methods of agriculture.—Not all the methods adopted by the native grower from plantation practice have been to his benefit, but better to appreciate this it is first necessary to refer briefly to his other crops; at the same time the opportunity for, and the extent of, the influence given by technical supervision will be seen. The staple food of the Chagga is the banana, which also supplies him with thatching material and food for his cattle, which are stall-fed. His banana plot is usually his main consideration. Apart from small areas of beans, yams, &c., the only other crops of importance are maize, which may be grown some

distance away below the main coffee-belt, and eleusine for the manufacture of beer. The banana plots are situated in the coffee-belt, and each family occupies a hut amongst his bananas. The basis of this system, which allows of no rotation for the main banana crop, is the cattle population. There is practically no vacant land for grazing, frequently insufficient even for the beasts to exercise; therefore the Chagga stall-feeds his stock. He feeds them on bananas and on veldt grass, the latter being carried by his womenfolk over long distances from the plains. Formerly, most of the manure went back to the bananas, but with the inclusion of coffee into the system an increasing share of the manure is made available for the coffee. The Chagga is ready to adopt any measures which will establish his coffee more firmly and make it more productive, and his line of reasoning is that, if it pays the European to purchase cattle dung for his crop, it must be good practice. It is becoming increasingly difficult for Europeans to purchase cattle manure from natives.

The greater part of the native-owned coffee has been planted among the bananas and, where the necessity for thinning out the latter to make room for the coffee has been recognized, the coffee has flourished under what are almost ideal conditions. The heavy mulch of decaying organic matter is effective in preventing soil wash on even comparatively steep slopes, soil moisture is maintained, weed-growth is controlled, and the bananas themselves provide shade and protection from wind. Generally the indigenous forest trees (particularly *Albizzia* spp. and *Rauwolfia inebriens*) have been left in, and with bananas to provide an excellent soil mulch no other cultivation is necessary. That farm-yard manure should be the basis of this system is evident when one sees coffee in a banana plot which, perhaps because the owner is a bachelor and has not built and stocked his house, is unmanured; in this case the coffee makes very poor, spindly growth and is unable to carry even a small crop without showing signs of distress.

Unfortunately the ambitious Chagga is often tempted to extend his coffee beyond the limits of his banana plots, and perhaps opens up land some distance away. Following the example of many European planters, he may not put in shade trees, or not enough; he often maintains a more or less clean state of cultivation tending to the loss of much of his unprotected top soil through soil wash, and then endeavours to stimulate his flagging trees with excessive irrigation. Couch grass may become established and the disheartened owner either practically abandons the coffee, or mutilates its root-system beyond recovery in an endeavour to eradicate the couch grass. He may not be a cattle-owner or be in the position of the European who has been able to purchase supplies of manure from native neighbours; nor is he sufficiently advanced to endeavour to keep up or replace the lost humus of the soil with green manures, cover crops, or composts, to which planters are now giving their attention. These are the extremes of conditions of coffee cultivation by the Wachagga. Fortunately, the greater part approximates to that first described and the proportion of really poor coffee is on the decrease; in fact, public opinion among the native coffee-growers is often exerted towards the eradication of very unhealthy and uneconomic trees.

There are, however, many natives owning coffee plots, some of them 5 to 15 acres in extent, whose methods approximate very closely in every respect to those of the better European planter, but such a slavish imitation of plantation methods by peasant cultivators is not encouraged. The aim is that the native should be a peasant farmer in the real sense, with his food crops and his cattle plus a small plot of coffee which cannot become beyond his capacity to manage.

Although concerned also with propaganda for improved methods of cultivation, the staff of the Department of Agriculture, responsible for the care of native coffee, endeavoured at first to secure improvement through the enforcement of the Plant Pest and Disease (Coffee) Regulations. Under penalty of a fine, planters (both European and native) were obliged to maintain their coffee reasonably free of noxious weed-growth and to take appropriate action against pests.

During the last five years a sounder appreciation of the requirements of the coffee-plant, particularly with regard to soil conditions and development of the root-system, has led to some change of policy. A change in mind and temper of the native coffee-growers, and, generally, a change in the attitude of European planters towards them, have facilitated this change, thus enabling Agricultural Officers to devote more time to the teaching and demonstration of cultural methods without neglecting the control of plant-pests and diseases.

The Influence of the Native Authority.—It was realized that the planting of coffee by natives frequently led to the choice of exhausted or otherwise unsuitable land, the use of inferior planting material, and careless planting methods; and that such conditions resulted in weakly coffee, particularly liable to pest and disease. It also became evident that to enforce the cultivation of neglected coffee was uneconomical, since the digging necessary to eradicate deep-rooted grasses left the tree with a mutilated root-system, and under Kilimanjaro conditions such plants seldom, if ever, fully recovered. By means of rules enacted by the Native Authority on the advice of the Agricultural Officer, further plantings of coffee by natives were brought under strict control. For the last two seasons a permit has had to be obtained from the Agricultural Officer, or his nominee (usually the African Instructor of the sub-district), before a native could add to his existing coffee or open up a new plot. This permit is given only when the planter demonstrates that he has suitable land which is free from couch grass. The observance of certain conditions such as the completion of anti-erosion measures (terracing, or contour-trenching, with hedges) and the planting of shade trees, may be insisted upon. At the same time the native is instructed in planting methods. In the event of failure to comply with these conditions the coffee may be summarily uprooted by order of one of the European departmental officers, of which there are three concerned with native coffee on Kilimanjaro. All nurseries are subject to inspection and all unsuitable planting material is destroyed. By the control thus exercised it is possible to avoid at the outset those conditions which are conducive to the establishment of weakly and unproductive trees. Where coffee becomes derelict as the result of abandonment, or for other reasons, it is uprooted.

Pests and Diseases.—The three most important pests are thrips, which may cause heavy leaf-fall followed by die-back, the coffee bug (*Antestia lineaticollis* Stal.), which is the carrier of Coffee-bean Disease, and the White Stem-borer (*Anthores leuconatus*). Fortunately, the greater part of the native coffee lies above the altitude below which thrips causes most damage, so all that is required is to maintain supplies of pumps and lime-sulphur at strategic points and spray small areas that may be attacked, particularly in years of low rainfall. The coffee bug is a serious pest throughout the coffee-belt, causing considerable loss of crop wherever it is unchecked, and for the past three years an annual spray campaign has been carried out, requiring three sprayings at intervals of ten days. Some 18,000 of native-owned coffee plots are so treated. This is only possible by making use of the native co-operative organization, which has been mentioned above and is described below, for the movement of spray materials and the supervision of spraying, under the general direction of departmental officers. The stem-borer, like thrips, is confined to the lower altitudes, but approximately one-sixth of the native coffee is found in this belt. Every year, prior to the emergence of the adult borer-beetles from the coffee at the onset of the short rains, every coffee-tree in the borer-belt is examined; severely bored trees are uprooted and burned, and the borer-grubs removed from those only superficially bored. This work is also carried out by the individual growers under the supervision of departmental African instructors and field secretaries of the native co-operative society, who co-operate closely in all matters concerning coffee. It was established in 1932 that the coffee was being re-infected with borer from three species of wild shrubs that were common throughout the coffee areas of Kilimanjaro. In view of this, by communal effort, over 1½ million of these shrubs were uprooted and burned, with the object of reducing the danger of re-infestation of the coffee.

It has been amply demonstrated that the disease *Hemileia vastatrix* is mainly induced by cultural errors affecting both plant and soil; it invariably occurs on badly eroded soils. The rules made under the Native Authority for the control of plantings go far to avoid coffee which is conducive to Hemileia attack. Hemileia can be dealt with by spraying with Bordeaux mixture; this also appears to assist in the maintenance of leafage with subsequent increase in crop yields. Here again the influence of the European in demonstrating the value of Bordeaux spraying will be a valuable support to the propaganda and demonstrations of the Agricultural Officer.

The Co-operative Society.—This account would not be complete without some reference to the Kilimanjaro Native Co-operative Union, Ltd., of which every native coffee-grower on Kilimanjaro is a member through one or other of the twenty-seven affiliated subsidiary societies. All coffee grown by the members is marketed through the Union. The reason for the formation of the first society, mainly for defence purposes, has been described: it was not a co-operative society in a recognized sense and soon got into difficulties, which became so serious about 1930 that Government stepped in to assist in its reorganization. Mr. Strickland

visited Kilimanjaro to report on the question of co-operative societies, and the Co-operative Societies Ordinance was the outcome; under this the existing native association was reorganized with a European manager, and since then the society has gone from strength to strength. Of the 45,000 males over 18 years of age inhabiting Kilimanjaro, nearly 20,000 are coffee-growers and are members of the Union; some 10,000 males live in areas which are not suitable for coffee-growing. Not more than 10 per cent. of the cultivable land owned by the Chagga tribe is under coffee. The influence of the European manager is best seen from the following extract from the Annual Report of the Department of Agriculture for Tanganyika Territory for 1934:

'*Native Coffee*.—The production of native-grown coffee on Kilimanjaro reached the record output of 1,530 tons. The position of this industry must be regarded as good when compared to the unsatisfactory state of affairs of three to four years ago. In the Annual Report for 1931 it was stated that "the Kilimanjaro Native Planters' Association has been of little or no use to the department in the work of cultural improvement, neither have they been satisfactorily equipped with spray pumps and chemicals to deal with coffee pests and diseases". Again in regard to the marketing of the native-grown coffee crop it was noted that "departmentally we have been completely impotent to effect an improvement in this matter, which has greatly handicapped our work to effect improvements in both the culture and preparation of native coffee". All this has been changed, and the credit for the more satisfactory state of affairs is mainly due to Mr. A. L. B. Bennett, the manager of the Kilimanjaro Native Co-operative Union, and to Mr. C. Harvey, District Agricultural Officer, and his assistants, who in their work of the past four years have contributed largely to that close co-operation now existing between the society and the department, and which is so essential to our work and the aims and success of the society.

'In addition to marketing, the society has undertaken to carry out with our advice the organization of anti-pest and disease-control measures. The keenest interest is taken by all the native officials of the society in the regulations affecting coffee, and in all agricultural matters generally. They are invaluable and active in their assistance to the agricultural staff in the field, and form one of the best media for getting the peasant coffee-grower to react favourably to our advice. The force of public opinion alone is now sufficient in many areas to cause the eradication of derelict and pest-ridden coffee. In many areas there is similar close co-operation with the native chiefs. Where the native chiefs are not interested one may find the greatest obstacles to improvement, and there conditions are most backward.

'The two agricultural assistants concerned with native coffee have with their native staff made 20,467 inspections of bearing coffee, in addition to 6,242 inspections of newly planted coffee.'

The reorganization of the native association was primarily for the purpose of marketing the crop, as this had been carrried out in a competitive and most unsatisfactory manner, and at present marketing is still an important function of the Union. With the realization of the effect of united effort, the societies now take an active part in the promotion of better agricultural methods, and it is considered that these works, together with the collection of the crop, will become the most important functions of the Union, and that the actual disposal and realization of the crop will be left to some more specialized body.

Co-operation of the European with the Native.—The influence of the white coffee-producer passed from a benevolent phase to one of malevo-

lence, but has now arrived at the stage where there is a real desire for co-operation with the native coffee-producer. This was expressed at a meeting, held in Nairobi in 1934, of representatives from Kenya, Uganda, and Tanganyika of European coffee-growers in a resolution which, in general terms, stated that there should be no racial discrimination whatsoever between coffee-producers, and that coffee, whether grown by natives or non-natives, should receive similar treatment. It was inevitable that such an attitude should come about, but the present depression pervading the coffee markets of the world has caused a more ready acceptance of the position, for it was obvious that in the reorganization of marketing methods so ardently desired by the European grower it was impossible to leave out a class of producers whose output amounts this year to some 2,000 tons of coffee from Kilimanjaro, as well as over 10,000 tons of the Bukoba coffee, even though the latter is of a different class to the Kilimanjaro native and European-grown coffee. The value of bulk-marketing, especially of the lower grades, has been amply demonstrated by the Kilimanjaro Native Co-operative Union, prices being obtained this season which would have been impossible to achieve if the produce had been sold in small and uncontrolled lots, as the European produce is usually sold. By this means indiscriminate competition with European-grown coffee and dumping on over-loaded markets should be avoided. It is interesting to note that the European coffee-growers in East Africa are studying the methods by which bulk and controlled marketing, of their lower grades especially, can be achieved. The point of competition of native-grown coffee can be over-stressed, however, for although Tanganyika, including Bukoba, produces about one-quarter of the amount of coffee grown within the Empire, the amount of coffee grown by natives on Kilimanjaro in 1934 was but one-fortieth of this, or one-half of one per cent. of the total effective world stocks.

Research and Investigation.—The interest shown by the Wachagga in the Coffee Research and Experiment Station, recently opened on Kilimanjaro, is in accordance with his general attitude towards his coffee. He will not accept what is told him without careful thought and, maybe, argument; but, once he is satisfied that what is proposed will benefit his coffee, he will support the proposal to the limit of his resources of labour or actual cash. The natives assist equally with Europeans in financing the station, and they are showing keen interest in its work.

Perhaps the best tribute that has been paid to the Kilimanjaro native coffee-grower is that of an experienced European planter from a neighbouring colony, who, being a little fearsome at the extent of native production, on account of competition, made a tour of the native coffee areas and summed up his opinion in four words: 'It is disappointingly good.' It can be said that the European planter himself has been, perhaps unwittingly, the strongest influence of all in achieving this not unsatisfactory standard of native coffee culture, for sustained and continued contact and example, as is given by the European coffee industry to that of the native, is most effective.

Tribal customs may also become affected by the influences which have made the native coffee industry what it is to-day. The crop has considerably

enhanced the value of land in the eyes of the native; at the present time the land is the property of the tribe, held in trust by the chiefs, who act with the advice of their councils. A tribesman is allotted a plot to utilize to the best advantage; such allocation does not confirm ownership of the land but only the crops and buildings thereon. If the cultivator fails to make good use of the holding, it may revert to the pool and be re-allocated. This custom ensures that the land is used advantageously, as a lazy occupier is always in fear of losing his plot to a more competent man, and, where coffee is grown, there is even greater incentive to better agricultural methods and possibly a desire for a more permanent form of tenure and individual ownership of land.

In conclusion I desire to acknowledge my indebtedness to Mr. A. L. B. Bennett, the manager of the Kilimanjaro Native Co-operative Union, to Mr. R. M. Davies, Senior Agricultural Officer, Moshi, and especially to Mr. C. Harvey, District Agricultural Officer, all of whom have materially assisted in the preparation of this paper.

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Laboratory of the Coffee Research and Experiment Station, with Kilimanjaro in the background

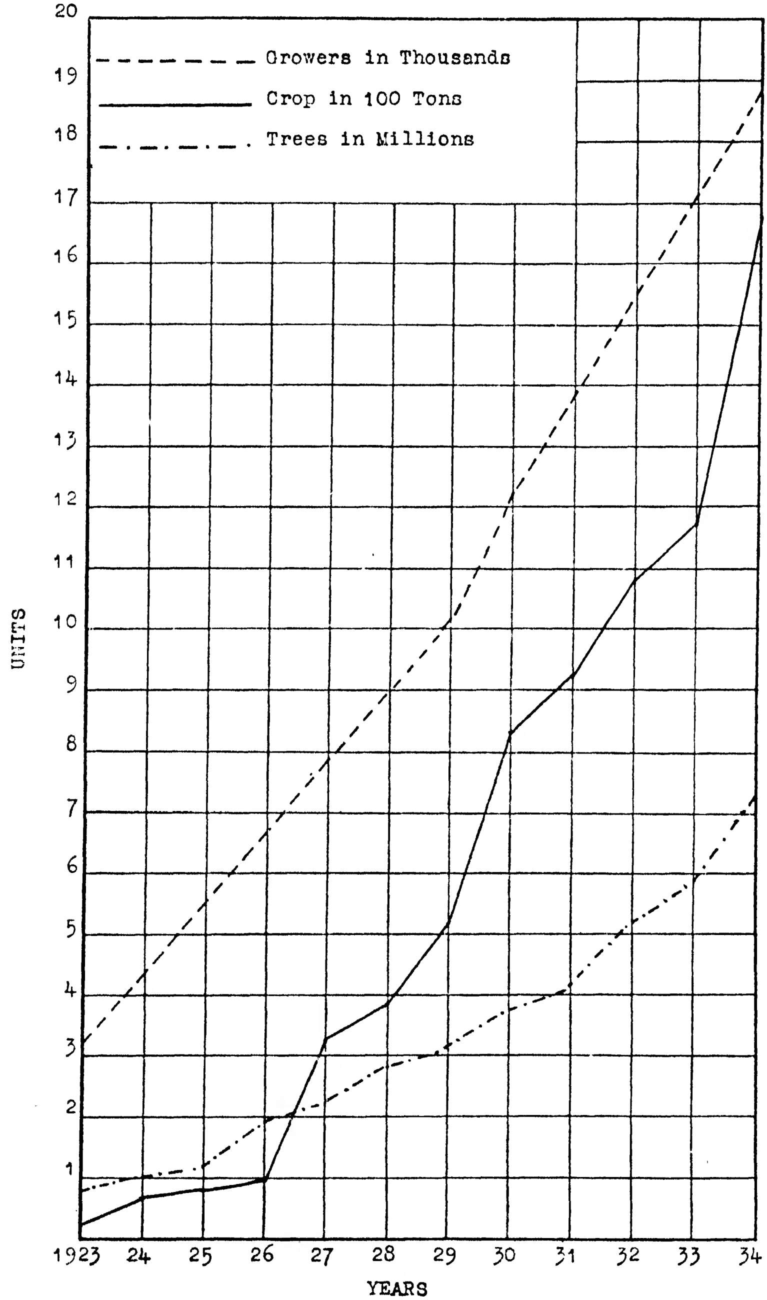
Young native-planted coffee on sloping land which has been terraced or contour-hedged

Young coffee with light banana shade. (Contour-trenches are being made)

An example of good native coffee on Kilimanjaro

Branch Office of the Kilimanjaro Native Co-operative Union

PROGRESS OF NATIVE COFFEE PLANTING AND PRODUCTION ON KILIMANJARO



THE WEIGHTS OF THE CARCASS AND OF THE INDIVIDUAL ORGANS IN THE BODY OF CATTLE IN KENYA COLONY

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WITH PLATE 9

IN a previous article [1] the distribution of weight between the carcass and the other parts of the body was determined for the zebu cattle in Tanganyika Territory. In view of the possible development of an East African meat industry it was thought advisable to get similar figures for the cattle in the neighbouring colony of Kenya.

Kenya has developed into a 'white man's colony' very much more than has Tanganyika Territory, and much of the highlands has been settled by European farmers. The natives have been removed from these alienated areas and are allowed to follow their pastoral and agricultural pursuits only in their native reserves. It becomes necessary, therefore, to divide the live stock of Kenya according as it is owned by Europeans or by natives.

Native-owned Cattle

The native-owned stock will be considered first because it is of pure zebu origin and closely comparable with the zebu stock in Tanganyika Territory. The conditions in which the Tanganyika cattle live have been described [1]. As one would expect, the importance of cattle in the social life and the system of animal husbandry practised in the Kenya Native Reserves are identical with the conditions in Tanganyika Territory, because the international boundary does not follow the tribal boundaries, parts of one and the same tribe being found in both territories. As in Tanganyika Territory the native thinks far more of quantity than of quality. Thus we find that overstocking is common; it is responsible for much erosion, poor pastures, stunted and thin stock, and, at certain periods of the year, of starving animals.

As shown for Tanganyika Territory the condition of the cattle slaughtered varies with the season of the year and the district in which they have been reared. For further details concerning native stock the previous article [1] should be consulted.

All the cattle examined in this investigation were slaughtered in the Nairobi Municipal abattoir between August 11 and 23, 1935. At this period of the year the cattle may be considered in average condition between the good period of the year at the end of the long rains and the worst part when grazing and water are both scarce.

The native cattle slaughtered in Nairobi are all purchased from natives at the collecting stock-markets in the Reserves, and are eventually bought from the traders by the Indian butchers in the township. As cattle are bought from several Reserves it was impossible to divide the cattle slaughtered according to their place of origin. Generally, however, it

appeared that the Machakos cattle were smaller than the Masai, and the Boran cattle were much larger than those from any other Reserve. If the large Boran stock be excluded the remainder resembles in size the cattle in Tanganyika Territory, though perhaps they are usually a little larger.

As in Tanganyika the Kenya natives are very reluctant to part with female stock, and during the period of the present examination so very few female cattle were brought to the abattoir that they were not recorded.

The parts of the body weighed and recorded below are the same as for the Tanganyika stock, and reference to the article quoted [1] will explain the various headings.

No estimations were made of the weight of blood in the cattle because of the delay that would have been caused in the abattoir, and because of the difficulty of accurately collecting blood from an animal slaughtered by having its throat cut. As there is little difference in size between the majority of the Kenya zebu cattle and the Tanganyika cattle it can be expected, from measurements on Tanganyika cattle, that the blood-weight of Kenya cattle will be approximately 20 lb. per beast.

No weigh-bridge is attached to the Nairobi abattoir, so that live-weights before slaughter could not be ascertained. The cattle after slaughter were examined by the Meat Inspector, and the carcass and organs were weighed before they had become cold. This means that the loss in weight due to cooling must have been very small, and so a very close approximation to the actual live-weight can be obtained by adding all the body components and allowing a 2 per cent. loss due to cutting up the carcass, &c.

TABLE 1. *Average Weights in Pounds of Carcass and Individual Organs of Native Zebu Cattle*

Type of stock	*2-Tooth cattle*	*4-Tooth cattle*	*6-Tooth cattle*	*Full-mouth cattle*	*Full-mouth oxen, carcass over 350 lb.*
No. recorded	21	20	23	214	58
Carcass	183·2	205·5	222·8	308·5	384·8
Head	16·4	19·0	20·9	23·9	28·5
Hide	29·2	31·5	35·5	43·4	52·0
Feet	9·4	10·5	12·3	12·8	13·4
Tongue	1·6	1·6	1·9	2·5	3·0
Tail	1·1	1·2	1·3	1·6	2·1
Liver	5·5	5·6	6·9	8·3	10·0
Lungs	4·2	4·5	4·8	7·0	8·3
Kidneys	0·9	1·0	1·1	1·2	1·5
Spleen	1·0	1·3	1·5	1·8	1·9
Heart	1·2	1·3	2·2	2·3	3·1
Suet fat	1·4	2·3	3·0	3·9	5·0
Caul fat	3·0	2·8	3·9	5·6	7·4
Contents of alimentary canal	53·3	64·7	67·8	90·4	108·4
Stomachs and intestines	26·0	25·5	34·2	40·4	42·6
Hump	2·6	3·9	4·8	5·1	7·2

From the figures in this table we calculate that the average live-weight of the full-mouthed native cattle slaughtered in Nairobi is 590 lb. This is about 80 lb. heavier than for similar cattle in Tanganyika. The carcass-weights varied from 212 to 475 lb., and the average of 308·5 lb. is over 40 lb. heavier than for the zebu cattle measured in Tanganyika. Further comparisons between the cattle of the two territories show that the Kenya cattle have much the heavier hides but the lighter heads. The feet, stomachs, intestines, tongue, liver, and omental fat are all heavier in the Kenya stock. The hump, on the other hand, is larger in the Tanganyika animals.

Table 2 shows the average live-weight of the full-mouthed stock from the two territories, together with the proportional distribution of weight in the body.

TABLE 2. *The Live-weights and their Distribution in the Body of the Zebu Cattle in Kenya and Tanganyika Territory*

	Kenya Colony				*Tanganyika Territory*			
	Full-mouthed cattle		*Full-mouthed cattle over 350 lb. carcass*		*Full-mouthed cattle*		*Full-mouthed cattle over 350 lb. carcass*	
	Weights (lb.)	*Weights as % of live-weight*	*Weights (lb.)*	*Weights as % of live-weight*	*Weights (lb.)*	*Weights as % of live-weight*	*Weights (lb.)*	*Weights as % of live-weight*
Live-weight	590	100	715	100	510	100	700	100
Carcass	308·5	52·3	384·8	53·8	260·4	51·1	381·1	54·4
Head and horns	23·9	4·0	28·5	4·0	28·1	5·5	34·7	4·9
Hide	43·4	7·3	52·0	7·3	31·6	6·2	43·6	6·2
Feet	12·8	2·2	13·4	1·9	10·6	2·1	11·8	1·7
Stomachs and intestines	41·4	7·0	42·6	6·0	34·1	6·7	44·3	6·3
Contents of alimentary canal	90·4	15·2	108·4	15·2	84·4	16·5	91·3	13·0
Tongue	2·5	0·4	3·0	0·4	2·2	0·4	2·7	0·4
Tail	1·6	0·3	2·1	0·3	1·5	0·3	1·7	0·2
Liver	8·3	1·4	10·0	1·4	7·1	1·4	8·8	1·2
Lungs	7·0	1·2	8·3	1·2	7·4	1·4	9·3	1·3
Heart	2·2	0·4	2·3	0·3	2·1	0·4	2·9	0·4
Kidneys	1·2	0·2	1·5	0·2	1·4	0·3	1·6	0·2
Spleen	1·8	0·3	1·9	0·3	1·8	0·3	2·0	0·3
Suet fat	5·6	0·9	7·4	1·0	4·1	0·8	9·4	1·3
Caul fat	3·9	0·7	5·0	0·7	3·8	0·8	9·5	1·4
Hump	5·1	0·9	7·2	1·0	5·9	1·2	12·0	1·7
Blood	20·0	3·4	25·0	3·5	18·1	3·5	25·0	3·6
Loss	..	1·9	..	1·5	..	1·1	..	1·5

The figures in this table show that the tongue, tail, liver, lungs, heart, spleen, and kidneys form the same proportional weight of the total body of the cattle in both territories. The average carcass-percentage of the full-mouthed cattle in Kenya is slightly above the percentage yield for the average of the Tanganyika full-mouthed animals, but the reverse holds true for the bigger cattle yielding a carcass of over 350 lb. The most striking differences are the heavier hide of the Kenya stock, and the heavier head of the Tanganyika cattle.

Beyond nutritional retardation of growth-rate there does not appear to be any obvious reason for these differences, yet a difference of over 10 lb. in the average green-weight of the hides will cause a marked increase in the value of the hides sold annually. It is also noteworthy that

the percentage weight of the hide in these Kenya native cattle is higher than is usually met with in improved breeds, and is higher than is found in the grade European stock of the Colony. The native cattle of Kenya are slightly heavier than those in Tanganyika, but the increased surface area, calculated as proportional to the (weight) $\frac{2}{3}$, is sufficient to account for a 0·1 per cent. increase in the area of the hide. From a few measurements on animals chosen at random it appears that the skin thickness is greater for cattle in Kenya than it is in Tanganyika (Table 3).

TABLE 3. *Average Thickness of Skin of Zebu Cattle in Tanganyika Territory and Kenya*

Place	Breed	No. of cattle measured	Skin thickness (cm.) Shoulder	Flank	Over 13th rib
Tanganyika Territory	Zebu	50	0·26	0·30	0·39
Kenya Colony . .	Zebu	50	0·37	0·44	0·65
Kenya Colony . .	European zebu grade	39	0·43	0·52	0·84

Trowbridge, Moulton, and Haigh [2] found that as a steer fattens the percentage-weights of carcass and fat increase, whilst the proportional-weight of other organs, with the exception of the stomach and liver, decreases. The figures in Table 2 for the average full-mouthed and the heaviest cattle in both Kenya and Tanganyika Territory are in general agreement with these American findings. However, the proportion of liver in these zebu cattle falls slightly in the Tanganyika stock, and the percentage of stomachs and intestines falls very decidedly.

The figures also indicate that the large Boran cattle and the biggest of the Masai oxen, which together represent the cattle yielding carcasses of over 350 lb., yield almost as high percentage returns of carcass and edible offal as do the improved animals, i.e. the zebu cattle graded up by bulls of European breeds. The slow-growing and smaller zebu cattle are usually regarded as much inferior to the improved grade European beasts for beef-production, but these figures suggest that, were the zebu cattle reared under the same good conditions as the 'grades', then the percentage returns would be the same or very little less.

It was not possible to divide the carcasses of the cattle slaughtered at Nairobi into quarters, as was done in Tanganyika Territory. The Indian butchers at Nairobi sell much of the forequarters as 'soup' meat, and the cut dividing the fore- and hind-quarters is made as far forward as possible; usually, however, 6 ribs were left on the hind-quarters. In 50 animals, however, the carcass was divided between the 10th and 11th ribs, and in these cases the hind-quarters represented 50 per cent. of the total carcass-weight. This compares very closely with the figure, 50·7 per cent., found in Tanganyika Territory.

European-owned Cattle

The European-owned cattle of Kenya can be divided into zebu and grade European breeds. A few farmers are rearing pure zebu cattle under

ranching conditions. These animals usually mature faster and grow into larger animals than do native-owned zebu stock, because they do not suffer such a severe degree of starvation as do the native-owned animals in the overstocked areas of the Native Reserves. Some of these European-owned zebu animals, chiefly of the Boran type, found their way into the Nairobi abattoir during the period of the present investigation. These have, however, been grouped with the full-mouthed zebu cattle yielding over 350 lb. carcasses.

The majority of European settlers own graded cattle. Zebu cows are bought and then graded up to a European bull, often of a dairy breed, such as the Friesian, Ayrshire, or Shorthorn. The female half-grade animals from one of these bulls are then crossed with pure or grade European bulls, not necessarily of the same breed as their father. Many of the grade animals slaughtered during this investigation were progeny of such mixed breeding. It was, therefore, impossible to group these grade animals according to the amount of European blood in their make-up, or to the European breed to which they had been graded up. It is important to remember, when examining the figures below, that these cattle were graded in the majority of cases to a dairy and not to a beef bull. Such grade dairy oxen grow quicker and develop into larger animals than do the zebu cattle, but they can never yield such good carcasses as could be obtained from cattle graded to a bull of an improved beef-breed.

The majority of the European settlers are marketing their slaughter stock through the agency of the Stock Breeders' Association. All the best European-owned cattle are bought by European butchers in Nairobi from this agency, whilst the Indian butchers buy only the poorer, older, or female stock left by the European butchers. In this investigation the grade cattle have been subdivided according to the butcher killing them, and those killed by the Indian butchers represent cattle rejected as not up to market requirements.

The average weights of the various tissues and organs of 100 grade stock slaughtered at Nairobi are given in Table 4.

We see at once the striking superiority in carcass-weight of these grade animals over the native zebu cattle: all their organs weigh more than the corresponding organs in the zebu breed. The figures also illustrate the tremendous difference that exists between the poor quality and the average grade stock. Even the average of the poorer grades killed by the Indian butchers were much heavier than the average of the heaviest native zebu cattle recorded in Table 2.

In the following discussion only the grade stock slaughtered by the European butchers will be considered, because the others are not up to the average. The carcass-weight varied in these animals from 442 to 700 lb. each, and the average of 558·9 lb. is 1·8 times the average weight of the native zebu cattle in Kenya. The hides ranged from 50 to 80 lb. each, and the average weight of 64 lb. is very good. The deposits of internal fat in these grades were on the average about four times as heavy as in the zebu.

The 100 grade animals killed during this investigation show an average carcass-weight of 502 lb. Mr. F. Raper, the Secretary of the Stock

TABLE 4. *Average Weights in Pounds of Carcass and Individual Organs of Grade European Cattle*

Butchers	*European*	*Indian*		
Type of stock	*Full-mouth oxen*	*Full-mouth oxen*	*Full-mouth cows*	*2-Tooth stock*
No. recorded	60	29	6	5
Carcass	558·9	448·28	403·9	250·60
Head	36·20	28·22	29·50	22·50
Hide	64·01	55·35	56·67	30·40
Feet	19·50	15·46	13·84	12·20
Tongue	4·04	3·22	3·58	2·60
Tail	2·55	2·25	2·41	1·15
Liver	11·33	11·14	11·50	8·20
Lungs	10·98	10·54	11·00	6·20
Kidneys	1·88	1·76	1·90	1·05
Spleen	2·25	2·11	2·00	1·50
Heart	3·28	3·18	3·67	2·10
Suet fat	14·56	9·75	6·55	2·10
Caul fat	12·78	7·62	5·33	2·90
Contents of alimentary canal	129·76	115·72	121·50	87·60
Stomachs and intestines	57·87	47·44	53·00	36·60

Breeders' Association kindly let me look through his records for the last 18 months, and the average carcass-weight of the grade stock sold by this Association was 496·7 lb. for 2,363 animals. This means that the animals examined were typical of the grade animals slaughtered at Nairobi.

The hind-quarters of these grade carcasses formed 51·5 per cent. of the total carcass-weight. This compares very well with Fourie's figures [3] for South Africa (51·1 per cent.), and with the figures for the native zebu cattle (50·4 per cent.).

From the figures in Table 4 we can calculate that the average live-weight of these grade animals was 970 lb., with a blood-content of 30 lb., and a loss of about 1·5 lb. in opening up and splitting the carcass. For the Indian-killed grades the average live-weight works out at 800 lb.

In Table 5 are given percentage weights of the various tissues and organs in the bodies of these grade animals.

The carcass-percentages of the Kenya grade cattle are therefore higher than for the zebu animals. They compare well with the figures given by Chalmers [4] for Argentine (56 per cent.) and Uruguay (53·6 per cent.) cattle. The figures obtained by Hammond [5] are for animals slaughtered at the Smithfield fat-stock show, and are therefore for cattle in a much fatter condition than the market normally requires. Wentworth [6], from experience at Chicago, states that good steers yield from 56 to 59 per cent. carcass, and that cattle in show condition will yield up to 64 per cent. of their weight as carcass. The Kenya grade stock therefore kills very well, and were the animals beef-grades instead of dairy-grades there is no doubt but that they would be very suitable for export as chilled beef.

The carcasses of Kenya native zebu are very similar to those described for Tanganyika zebu cattle [1]. They are too small for export to Great

TABLE 5. *Percentage Distribution of Weight in Grade Cattle*

	Grade cattle		*Average British breeds* (4)	*Average American breeds* (5)
	European-killed	*Indian-killed*		
	Weight as % of live-weight	*Weight as % of live-weight*	*Weight as % of live-weight*	*Weight as % of live-weight*
Live-weight	100	100	100	100
Carcass	57·2	56·0	64·6	58·3
Hide	6·6	6·9	6·7	6·3
Head and horns	3·7	3·5	3·9	3·8
Feet	2·0	1·9		
Stomachs and intestines	5·9	5·9	..	..
Contents of alimentary canal	13·4	14·5	..	..
Tongue	0·4	0·4	0·8	..
Tail	0·3	0·3		
Liver	1·2	1·4	2·6	2·9
Lungs	1·2	1·3		
Heart	0·3	0·4		
Kidneys	0·2	0·2	..	..
Spleen	0·2	0·3	..	..
Suet fat	1·5	1·2	..	..
Caul fat	1·3	1·0	..	..
Blood	3·1	3·1	..	3·8
Loss	1·4	1·7	..	..

Britain as chilled or frozen meat, and are far more suited for a local packing industry.

The grade carcasses as a whole are a little too small for the frozen- or chilled-meat markets. There are, however, about 50 per cent. which weigh over 600 lb. carcass-weight, and these would be suitable. The heavier-grade carcasses are much better finished than the ordinary zebu carcass, though carcasses from good Boran or Masai oxen carry a nice covering of external fat and a fair percentage of intermuscular fat. 'Marbling', however, is not seen often, even in good zebu carcasses. The grade animal has, however, the ability to deposit fat intramuscularly.

The grade carcass generally is longer, the ribs have a better spring, the sides are deeper, and the meat is thicker than in a zebu carcass. The shins are better fleshed, there is more meat on the aitch-bone and rump-joints, and the thighs are also better developed. The insides and backs of the thighs are covered with a thin layer of fat, which extends over the rump and along the back and sides of the carcass to the shoulders. Generally, there is also a little fat covering the insides of the ribs, and a large deposit on the kidneys. It is, however, in the better distribution of fat among the muscles that the grade scores most over a good zebu carcass (Plate 9). In Kenya the slaughter stock are all grass-fed and, as was noticed in Tanganyika, there is a definite tendency for the fat covering a carcass to become very yellow, thus detracting considerably from the market value of the meat. The grade cattle examined appeared to be very heavy-boned, but no figures could be obtained to check this point.

FIG. 1 FIG. 2

The carcass of an average grade ox

Much, however, could still be done to improve the carcasses of grade cattle by introducing blood of a good light-boned breed, such as the Aberdeen Angus. Such crosses will be just as early maturing, but in addition will possess a high ratio of meat to bone in the carcass, and a greater development of the higher-priced joints.

Summary

Figures have been produced to show the actual and the proportional distribution of weight in the body of zebu and grade European stock in Kenya Colony.

Comparisons have been made between the zebu carcasses of Kenya and those in Tanganyika Territory.

The grade carcasses have been compared with those from other meat-producing countries.

It has been shown that Kenya possesses grade meat suitable for export, but that an improvement would result in the use of good bulls of a beef-breed.

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THE OCCURRENCE OF A BRITCH-POLL FIBRE-TYPE ARRAY GRADIENT IN THE NEW ZEALAND ROMNEY LAMB

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In a recent paper Dry [1] gives an account of the fibre-type arrays occurring on the back of the New Zealand Romney Lamb. Preliminary observations had suggested that orderly relations existed between the fibre-type arrays on the back and britch positions. These observations were extended and a comparative study of the fibre-type arrays occurring in the coat of the Romney lamb was made.

Material and Methods

The Romney lambs used for this work were from Dry's experimental Romney flock [2]. They were sampled from the following positions, which have been conveniently named (Fig. 1):

1. *Poll*: on the mid-dorsal line between the ear and horn positions.
2. *Anterior withers*: on the mid-dorsal line at the level of the last cervical vertebrae.
3. *Point of shoulder*: on the point of the right shoulder-bone.
4. *Withers*: on the mid-dorsal line, level with the fifth rib.
5. *Fifth rib*: on the right fifth rib, ventro-lateral to the withers in a line with the lateral aspect of the shoulder-point and dorsal to the elbow.
6. *Elbow*: on the elbow-joint of the right forelimb.
7. *Back*: on the mid-dorsal line, level with the last rib.
8. *Side*: on the right side, at the distal end of the last rib.
9. *Superior ileum*: on the mid-dorsal line on the medial angles of the ilea.
10. *Hip-joint*: on the junction of the femur and pelvic bones (acetabulum) and ventro-lateral to the superior ileum position.
11. *Stifle*: midway and slightly anterior to an imaginary line drawn between stifle and hip-joint.
12. *Britch*: immediately posterior to the stifle joint and midway across the thigh.
13. *Brisket*: on the mid-ventral line between the forelegs.
14. *Point of sternum*: on the mid-ventral line level with the shoulder-point position.
15. *Epigastric*: on the mid-ventral line immediately opposite the back position (No. 7).

The last three ventral positions were not taken regularly and the gradients given are for the dorsal and dorso-lateral regions only.

The method of examining the samples was simple; the fibres had been protected from the weather by coats of waterproof material, as described by Dry [3], the lambs being covered before the halo hairs began shedding.

Sorting was carried out on black velvet, using blunt-tipped forceps. Each sample was sorted into the following groups of fibres:

1. Halo hairs Sub-halo hairs Sickle fibres Super-sickle fibres	Shedding group
2. Curly-tipped fibres Checked curly-tip Peak curly-tip Other curly-tip 3. Histerotrichs	Non-shedding group

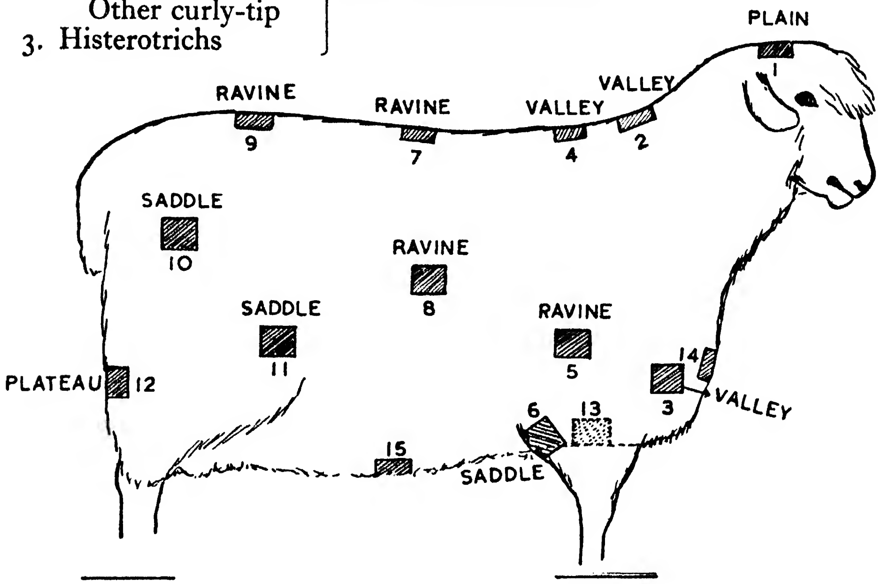


FIG. 1. Diagram to illustrate positions from which samples were taken.

1. Poll	6. Elbow	11. Stifle
2. Anterior withers	7. Back	12. Britch
3. Point of shoulder	8. Side	13. Brisket
4. Withers	9. Superior ileum	14. Point of sternum
5. Fifth rib	10. Hip-joint	15. Epigastric

On the diagram, the types of fibre-arrays found in one lamb in certain of the sampled areas (1–12) are named. The particular lamb (no. 745) is one of those shown on Graph III, which should be consulted for other types of distribution.

Halo hairs are the coarsest of the shedding fibres in the birth-coat; they are straight-tipped. The sub-halo are smaller and have a slightly curved tip. Sickle fibres have a distinct, thickened, sickle-shaped tip, demarcated from the shaft by a definite neck, but are the finest of the birth-coat fibres, which belong to the shedding group. The super-sickles are stouter and larger than the sickle fibres, possess no distinct neck, and represent a transition stage between the sickles and the sub-halo fibres. It is possible to determine a definite transition in these four fibre-types, from coarse halo hairs through sub-halos and super-sickles to the finer sickle fibres proper.

Curly tips of all varieties together constitute about two-thirds of the total fibres present in the birth-coat. Those designated 'checked curly-tips' are very fine, and have a number of curls in their tips. (It will be noted later that these fibres are found only in Valley, Plain, and Escarpment arrays.) 'Peak curly-tips' are the coarsest of the curly-tip group.

They are not found in fine arrays. Their tips have always a few curls. The remaining curly-tip fibres occur as later-growing fibres which have progressively finer tips with fewer and fewer curls.

Histerotrichs are relatively scarce, appear latest, are shorter, and are always very fine.

The samples were sorted into the above type-groups with little or no difficulty, the characteristics of the great majority being sufficiently marked to enable them to be immediately classified. It should perhaps be noted here that the above order is that in which the fibres are developed in the foetal skin. This is significant in relation to a previous study [4] in which it was shown that there are definite orderly phases of initiation of follicle-development and fibre-growth. Follicles are arranged primarily in threes, and then in nines. It is surmised that the three-stage of development gives rise to the shedding group (above), whilst the additional follicles which develop to constitute the nine-stage are responsible for producing the non-shedding type of fibres.

The Fibre-type Arrays

It has been postulated [4] that the fibre-type arrays were due to the action of two variables, (1) the prenatal check, and (2) the reduction in inherent coarseness. Prenatal work has suggested that these two phenomena are the result of the same physiological factor in the development of the fibre-population, viz. overcrowding of available skin-space due to rapid follicle-formation—the first occurring at the trio-stage, and the second at the nine-stage. The prenatal check, it was suggested, might be termed the 'trio-depression' and the reduction of inherent coarseness the 'nine-depression'.

The fibre-type arrays found have been conveniently named by Dry [1]:

Plateau (least depressed)
Saddle
Ravine
Valley
Plain and Escarpment (most depressed).

The Plateau array.—In this the trio-depression was so slight that it had no visible effect on the early fibres, no sickle fibres being present. Shed and persistent halo hairs and peak curly-tips represented the early fibres of the array-series. The nine-depression did not occur until at least half-way along the curly-tip portion of the array. There was a marked break between the fine and coarse curly-tips; this break occurred earlier in the array-series in samples from more anterior positions than in those from more posterior regions.

The Saddle array was due to weak trio- and nine-depressions. The nine-depression takes place about the same time in both Saddle and Plateau arrays.

The Ravine array had an intense, and often very intense, trio-depression of fairly short duration. There was always a marked rise in the coarseness of the post-ravine sickle fibres. The nine-depression occurred after the rise in coarseness in the post-ravine sickle fibres; there may or may not be a definite break between fine and coarse curly-tip fibres.

The Valley array showed an intense trio-depression of longer duration than in the Ravine array, there being no rise in coarseness until some of the early-checked curly-tips had been formed. The nine-depression took place shortly after the trio-depression had ceased to function.

The Plain array.—The trio- and nine-depressions overlapped in this array, and no increase in coarseness took place either in the sickle-fibres or in the curly-tip portion of the array-series.

The Escarpment array.—This new array (Fig. 2) was similar to the Plain, but no sickle fibres were present. It has been suggested that the escarpment was due to the overlapping of the nine-depression with a very intense trio-depression. This array has been found only once on any position other than the poll—on the britch of a very dense Romney; the array on the back was Plain; no other samples were preserved. It occurred frequently on the poll.

It has been suggested that the order of the fibre-type arrays was due to an increase in the intensity of the trio- and nine-depressions, those with the least intense depressions having coarse fibres, and those with more intense depressions finer fibres. Each of these arrays passed gradually into the next; all varieties intermediate between one fibre-type array and the next have been observed on different animals, and over the same animal.

Distribution of the Arrays

Preliminary examinations showed that different fibre-type arrays occurred on back and britch positions. It was known that fibre-type arrays passed gradually from one to the other (*v.s.*). From these two facts it was suspected that all fibre-type arrays separating the array on the back from the array on the britch would be found somewhere on the area intervening between these two positions. This was found to be true. Further, knowing that the arrays on the back and britch positions differed, it was expected that the arrays on the positions anterior to the back would differ from those on the back; this surmise was also found to be correct. As well as revealing that fibre-type arrays on back and britch positions differed, the preliminary examinations indicated that orderly relations existed between back and britch, the array on the back always being more depressed than the one on the britch.

More detailed work, involving the study of the fibre-type arrays occurring over the bodies of various Romney lambs, demonstrated that orderly variation from position to position was the rule for the distribution of fibre-type arrays over the body of the Romney lamb (Graphs II, III, p. 123 and Fig. 1).

This orderliness in variation was mainly due to less depressed arrays being posterior to more depressed ones, though, as explained later, some elaboration of this general statement was required.

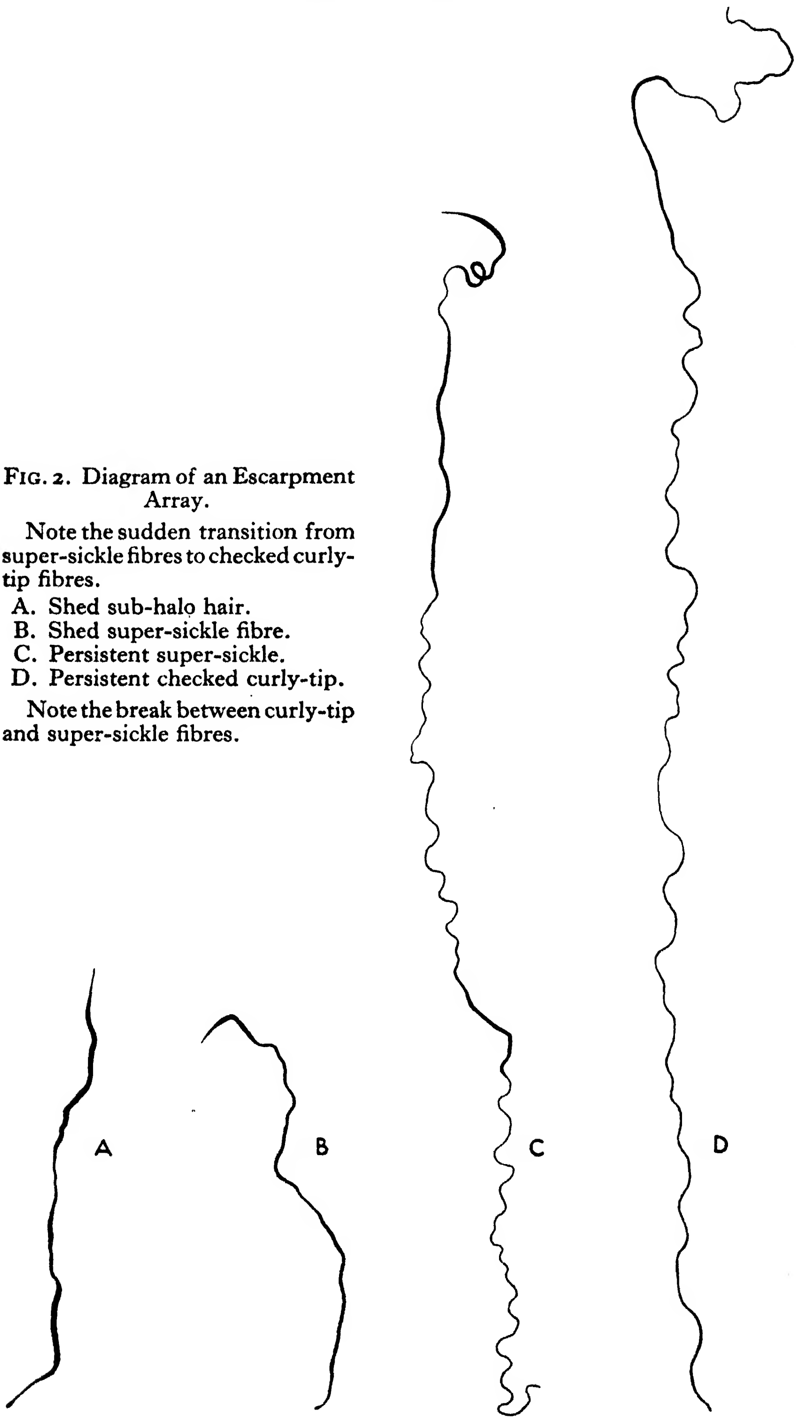


FIG. 2. Diagram of an Escarpment Array.

Note the sudden transition from super-sickle fibres to checked curly-tip fibres.

A. Shed sub-halo hair.
B. Shed super-sickle fibre.
C. Persistent super-sickle.
D. Persistent checked curly-tip.

Note the break between curly-tip and super-sickle fibres.

From these statements it was apparent that the gradual increase in fineness caused by the incidence of a check (depression in follicle-activity) from posterior to anterior regions resulted in a general posterior-anterior, or britch-poll fibre-type array gradient (Graphs II, III).

Besides the britch-poll gradient there must be kept in mind the subsidiary gradients due to gradual increase in coarseness of the fibres as one passes from dorsal to lateral positions in the coat of the Romney lamb (Graphs II and III).

It was found that the general gradients varied in steepness from animal to animal. Fine even-coated lambs and their opposites, the very coarse-coated animals, had very slight britch-poll gradients (Graphs II, III, sheep nos. 755 and 618). These two lambs resembled one another in that both exhibited slight britch-poll gradients, though at different planes. They were unlike in that No. 618 (Graph II) showed an even gradient due to an intense overcrowding occurring at the trio- and nine-stages of development, and resulting in a fine even fleece.

In no. 755 (Graph I), follicle-activity at the trio- and nine-stages of development had been very slightly affected by increasing density of the follicle-population in the skin, and the fleece in consequence was coarse, and very uneven in length and fineness. It may be noted here that this lamb, which is quite typical of its class, showed the characteristic 'break' which occurs between the coarse curly-tip and fine curly-tip groups, and all fibres developing later than the break were much shorter than the early ones.

These two sheep (Graph I, sheep nos. 618 and 755) did not exhibit such marked gradients as those given by the coats of the majority of lambs, but were indicative of the wide extremes of coarseness and fineness occurring in this breed of sheep; they also represent extremes in fibre-type arrays.

Other lambs of the Romney breed exhibited marked gradients from britch to poll (Graphs II and III, sheep nos. 641, 745, 628, 763). These graphs show general posterior-anterior gradients due to slight depressing on the britch passing to a deep depression on the poll.

These gradients were more or less characteristic of New Zealand Romney lambs. From the graphs it will be seen that the lambs can be separated into three classes, by their coat characteristic; i.e. fine, coarse, and intermediate:

Class	*Animal*	*Medullation*	*Graph*
	No.	Per cent.	No.
Coarse	755	50	I
	628	52	I
	745	54	I
	641	44	I
Intermediate	763	11	II
	619	18	..
	607	12	..
Fine	618	5	II
	638	4	II
	767	6	..

Substantiation of this grouping into three classes was supplied by the percentages of medullation found in the different coats. This medullation, though not indicative of fineness, suggested that unless the fibres were coarse medullation would not occur. The percentages of medullation were estimated by McMahon as explained in the footnote.[1]

It was found that animals of the coarse class showed not only marked variation in the fibre-type arrays occurring on the various positions but marked variation in fibre-length within an array. Also the fibre-diameter varied more in the coats of the lambs of the coarse class than in those of the fine or intermediate class. In the coats of the lambs of the fine class there was very little variation in either fibre-type array or in the length of the fibres comprising the arrays.

Thus we find that the Romney lambs can be divided into three classes: coarse, fine, and intermediate. In the coats of animals of the coarse class there is marked variation in fibre-type array, fibre-length, and fibre-diameter. In the coats of animals of the fine class there was little variation of any kind. The coats of animals of the intermediate class varied either more or less according as they approximated the fine or the coarse class.

Prevalence of the several fibre-type arrays on the various positions.—The following table gives an idea of the proportion of fibre-type arrays found on the different positions. These are from a number of animals selected at random and sampled from the same anatomical positions.

TABLE 1

Positions	*No. of sheep examined*	*Fibre-type Arrays in Proportion to One Another*				
		Plateau	*Saddle*	*Ravine*	*Valley*	*Plain and Escarpment*
Britch	100	30	**45**	13	9	Infrequent
Hip-joint	39	3	6	**26**	3	,,
Superior ileum	30	1	5	**18**	4	2
Back, Side	100	Infrequent	4	35	**42**	18
Withers, Fifth rib	46	,,	Infrequent	4	**21**	18
Shoulder point	44	,,	,,	2	19	**20**
Poll	35	,,	,,	Infrequent	3	**30**

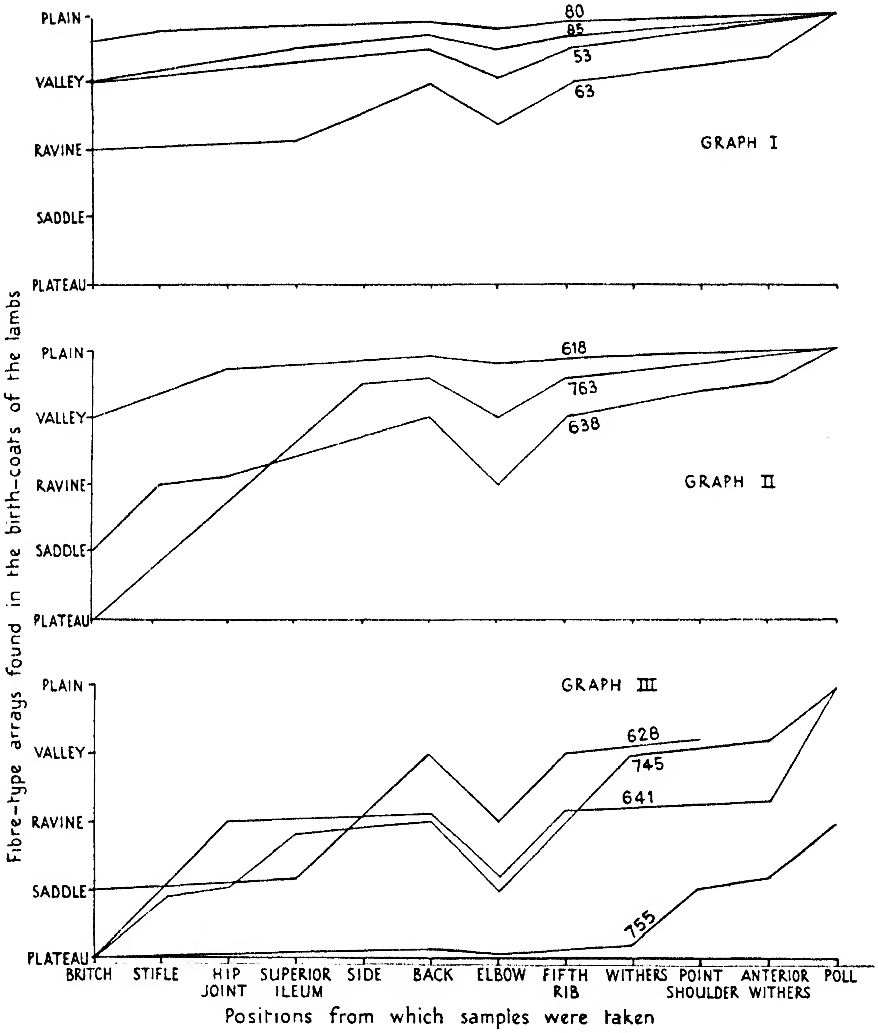
[1] *A method of estimating the medullation revealed in benzol.* By P. R. McMahon. When comparing samples the average percentage of fibre-material affected by medullation may be taken as an index of the degree of hairiness revealed by the benzol test. The following technique was evolved to obtain such a figure:

1. The staple is teased out to a standard thickness of 300 fibres to each inch of width by comparison with a standard staple obtained by direct counting.

2. The staple is immersed in benzol and with the aid of a photograph of a lock in benzol, spread to the same thickness and showing zones where 10 to 90 per cent. of the fibres are medullated, estimations of the percentage of fibres affected are made at ¼ in. intervals.

3. Taking these figures as representative, the average percentage of medullated fibre over the lock is calculated and expressed as one figure.

The technique is slow and cumbersome, but has been shown to be reasonably accurate for normal samples of wool. In the case of lamb's wool, however, the accuracy is considerably reduced by rapid changes in hairiness from one level in the staple to another, and also by the parallel placing of the fibres, which hinders accurate teasing. Differences of 7 per cent. would be significant.



To illustrate the general posterior-anterior (britch-poll) fibre-type array gradient in the Southdown, Ryeland, and Romney lambs studied.

GRAPH I

Southdown lambs nos. 80 and 85
Ryeland lambs nos. 53 and 63

Note the gradients are not very marked; the gradients of the Ryeland lambs, however, are slightly more marked than are those of the Southdowns.

GRAPH II. *The fine and intermediate class*

Romney lambs nos. 618, 638, 763

No. 618. *Fine Class.* Note the very slight britch-poll gradient and the very slight ascending gradient of the fore-limb.

No. 638. *Fine Class,* has a more general type of coat than that of No. 618; fine and

On the britch among the sheep examined it was found that Plateau was far more common than at first suspected. Dry [2], however, working on animals with no halo hairs on the back, found that these animals very rarely have a britch array so little depressed as a Saddle. Two of the Plateau arrays had a few halo- and sub-halo hairs, but a large number of super-sickle fibres and coarse Peak curly-tip ones. Plain and Escarpment were the most common arrays on the poll, Plain being more often found than Escarpment.

Ventral gradient of the Romney breed.—We have seen that there was a gradual posterior-anterior gradient over the dorsal and dorso-lateral regions of the Romney lamb due to gradual change from coarser to finer arrays as we passed from britch to poll. This same gradient, however, does not apply to the ventral and ventro-lateral region, for which another gradient would have to be drawn. No detailed work has been done on the ventral surface, but a few examinations indicated that the fibre-type arrays became coarser on passing from the anterior to the posterior end of the body. Further, they indicated that the fibre-type array on a position on the mid-ventral line was inclined to be slightly more depressed than one on a corresponding position on the mid-dorsal line. This was not very obvious on the sheep more characteristic of the Romney breed on positions anterior to the shoulder-point position. It is suspected that the posterior-anterior gradient for the ventral surface was similar to, but rather less steep than, that for the dorsal surface. Hence it can be seen that there is a general tendency for the more anterior positions to have more depressed arrays than the posterior ones, and that the most typical Romney lamb was a member of the intermediate class of lambs.

It was then necessary to ascertain whether a breed of sheep with a less variable fleece exhibited fibre-type array gradients similar to those of the New Zealand Romney.

Comparative Studies in Two Finer-woolled Breeds, Ryeland and Southdown

A small number of samples was taken from Southdown and Ryeland lambs—nine samples from four sheep of each breed and less from others

even but with a fairly marked gradient from the britch to the side. The fore-limb gradient is also more pronounced.

No. 763. *Intermediate Class,* has a marked britch-side gradient, but anterior to this the gradient is slight.

Graph III. *Coarse Class*

Romney lambs nos. 628, 641, 745 and 745

No. 755. Very coarse-coated, showing very little change in coat fineness till the shoulder-point position; gradient posteriorly is very slight but fairly marked anteriorly.

No. 628, „ 745, „ 641 — All show marked britch-poll gradients.

No. 628. (No anterior withers or poll sample taken.) Note the side-back gradient.

No. 745, „ 641 — Both very uneven-coated sheep.

—with the idea of determining the fibre-type array gradients for purposes of comparison with the Romney lambs.

Southdown lambs (Graph III, sheep nos. 80, 85).—The Southdown coat was very much finer and more uniform than the Romney coat; medullation rarely occurred. Air in the cortical cells, termed 'smokiness' by Rudall [5] and Elphick [6], occurred frequently. A few had halo hairs on the poll and a rather larger number on their britch margins; on many, however, halo hairs did not occur at all.

The arrays showed a very even distribution with very little gradient in the array-depression. Two animals with less depressed arrays on their britches than the others (Graph I, sheep no. 85) had some sickle fibres with medullated ends: these did not comprise the greater number of sickle fibres, there being far more very fine non-medullated ones. Some of these very fine sickle fibres were shed, but those with medullated ends were not shed; a few of the fine curly-tip fibres were also shed.

The animals with more depressed britch arrays (Plain arrays on the britch, Graph I, sheep no. 80) had few fibres with medullated sickle ends. Sickle fibres were numerous but extremely fine. On no sheep examined was an array less depressed than a Plain found anterior to the superior ileum position.

On one animal an Escarpment array was found on the poll. This animal had halo- and sub-halo hairs—short stout kemp fibres—and very fine super-sickle fibres succeeded by checked curly-tip ones.

The Southdowns examined were from one flock only and did not represent the extremes of coarseness or fineness that might be found in the breed. They can, however, be compared with those Romneys more characteristic of the breed. The Southdown gradients were not unlike the gradients of the extremely fine Romney lamb no. 618, Graph II, but they were generally far more even in array-distribution than those more typical Romney lambs (Graphs II and III, sheep nos. 641, 745, 628, 638, 763).

The Ryeland lambs (Graph I, sheep nos. 53, 63)—In many ways the wool of the Ryeland lambs was not unlike that of the Romney lambs (Graph II).

In the Ryeland the sickle fibres were like those of the Southdown but were perhaps a little coarser; sickle fibres with medullated ends were by no means restricted to the posterior regions. The sheep examined had fewer halo hairs than the Romney, and they were not so long. They were not, however, so free of these fibres as were the Southdown lambs. Shedding of fine sickle fibres took place as in the Southdown, but to a lesser extent.

In the curly-tip fibre portion of the array the resemblance to the coat of the Romney was quite marked. A considerable amount of medullation was present in some cases and in most there were traces of it. Compared with the curly-tip portion of the Romney, however, the Ryeland curly-tip fibres presented a more even series and exhibited less variation in length from fibre to fibre within the array; very coarse-tipped curly-tips were not found. The fibres as a whole were somewhat shorter than those of Romney lambs of the same age.

A Plain array was not found on the Ryeland britches studied, but Valley was common; Ravine arrays were found on two of the britches examined but nothing coarser was seen. The distribution of the arrays of these Ryeland lambs resembled the distribution of the arrays on the lambs belonging to the fine class of New Zealand Romneys (Graph II, sheep nos. 638, 618), but there was apparently far less variation in the fibre-type arrays occurring on different positions on the more average Ryeland lambs than there was in the more characteristic Romney lambs.

As in the case of the Southdown, the Ryeland lambs sampled were from one flock, and were therefore not indicative of possible extremes of either coarseness or fineness.

Though the numbers of sheep of these breeds examined were small, the observations made indicated that in both these breeds the distribution of fibre-type arrays was far less variable than in the Romney, and their coat generally finer and with less variation in fibre-length. The coat was shorter than that of the Romney, especially in the case of the Southdown.

Medullation was more common in the Romney, but not uncommon in the Ryeland lamb; the Southdown had very little of it, but those examined were inclined to show a considerable amount of 'smokiness' [5, 6].

Of the two breeds studied, the Ryeland more nearly approximated the Romney than did the Southdown in type of array and in character of fibre.

Shedding of Fine Fibres

Both Ryeland and Southdown lambs exhibited a marked tendency to shed their finer sickle fibres. Coarse super-sickle fibres and halo hairs were shed in a manner similar to the shedding of coarse fibres in the Romney breed. The Southdown also shed a few early fine curly-tip fibres. This shedding of fine sickle fibres was in marked contrast to the shedding of these fibres in the Romney, where shedding of all but those sickle fibres shed at birth, or very soon after, has been regarded as an expression of vigour [2]. Roberts [7], and Darling [8], in their papers on the Welsh mountain and the Scottish Blackface breeds, respectively, mentioned that shedding of fine fibres occurred, and dissociate it from the shedding of kemp. In their work on the Blackheaded Persian of South Africa, Duerden and Boyd [9] referred to a spring shedding of wool fibres as distinct from kemp fibres. In the Blackheaded Persian, however, all fibres of the coat were apparently shed. In the Southdown and Ryeland only the early fibres of the fibre-array type, the sickles and early curly-tips, were shed. In the Welsh Mountain breed [7], from the accounts given, the shedding was apparently similar to that of the Romney. In the Romney [2], shedding of kemp fibres was common. In addition to this, however, there was 'smoky' shedding due to the damaging of fibres [5]. Further, in one animal examined by Rudall it was found that there was shedding of the histerotrich fibres, possibly 'hunger' shedding. The manner of shedding of these differed from that of the early kemp fibres. Here the shed fibres did not have a bulb-like swelling

forming a sheath round the brush, nor did they have a 'smoky' swelling, as in fibres where the shedding was caused by the damaging of follicles. The brush was small, and the proximal portion of the shaft of the fibre very thin. In the Scottish Blackface the shedding of the fine fibres was apparently more nearly related to the shedding in the Blackheaded Persian than to that in the Romney breed.

The fine fibres shed by the Southdown and Ryeland were the early fibres of the array, the fibres that might form kemp in more hairy breeds. They were shed in a manner similar to that of the kemp of the Romney; each fibre had a bulb-like sheath about its brush, the bulb being visible to the naked eye when sorting on black velvet. These fibres were not those sickle fibres shed at birth or very soon after, though both these types were found in the Southdown and Romney breeds. Some of the shed curly-tip fibres of the Southdown had 'smoky' swellings, but not all, some being shed in the normal way.

From this we can say that the shed fibres of the Southdown and Ryeland lambs were of the same type as those fibres that constituted the kemp of the Romney, i.e. halo hairs, and coarse super-sickle fibres when present, and fine super-sickle and sickle fibres, and, as in the Romney, occasional curly-tip ones. The shedding of the fine curly-tip fibres of the Southdown was more common than the shedding of coarse curly-tip fibres of the Romney, which usually takes place to any extent only in Plateau and very occasionally in Saddle and Ravine arrays.

In a personal communication, Dry reported that one fine-woolled Romney lamb exhibited shedding of fine sickles in a manner similar to that of the Southdown and Ryeland. This was accompanied by the shedding of coarse kemps as well.

The method of shedding in these two breeds was similar to that of the kemp of the Romney, a thinning of the fibre succeeded by a brush in a sheath forming a bulb-like swelling. 'Smoky' shedding occurred in all three breeds.

Summary and Discussion of the Distribution of the Fibre-type Array

1. *Britch-poll gradient.*

In the New Zealand Romney, the Southdown, and the Ryeland, the extent to which the fibre-type arrays were observed to be depressed varied over the body, giving a general gradient from britch to poll, i.e. a posterior-anterior gradient; this gradient was gradual, no sudden transitions, such as Plateau on the britch to Plain on the superior flank position, taking place.

2. *Subsidiary gradients.*

The gradients up the sides of the body were subsidiary to the general posterior-anterior gradient, but accompanied it; they were most noticeable up the limbs. In these gradients the array on the inferior position limited the array on the superior position; thus the array on the britch limited the arrays on the rest of the body to being no less depressed than that on the britch.

3. *Variation in fibre-length*

The length of the fibres comprising the array series varied from the anterior to the posterior end of the body in accordance with the fibre-type array. Variation in fibre-length was less in the more depressed arrays, Plain and Valley, than in the less depressed Plateau and Saddle arrays.

4. *Shedding*

Shedding of the kemp in the Romney is regarded as an expression of vigour. Similar shedding affecting the coarser fibres was observed in the Ryeland and Southdown lambs. Shedding of the fine fibres also occurred in these breeds.

5. *Medullation*

Some medullation occurred in all of the Romney coats examined, but there was marked variation in the percentages found in different coats. A higher percentage of medullation was found in coats with slightly depressed arrays and a lower percentage in those coats where the arrays were more depressed. In the Southdown breed, medullation was negligible; it was more common in the Ryeland breed.

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IRRIGATION-DEVELOPMENT IN AUSTRALIA WITH SPECIAL REFERENCE TO IRRIGATION-SETTLEMENTS OF THE STATE OF VICTORIA

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WITH PLATE 10 AND MAP

THE conservation of water for irrigation purposes, and the construction of irrigation-systems for distributing the water, have proceeded steadily in Australia since 1886. The rate of progress is illustrated by reference to the State of Victoria. The total capacity of storage within the State at June 30, 1934, was 1,243,870 acre-feet, and on completion of works in course of construction will amount to 1,290,570 ac.-ft., as compared with 172,000 ac.-ft. in 1902. Furthermore, the Hume reservoir on the Upper Murray is completed to a capacity of 1,250,000 ac.-ft., and is designed for an ultimate capacity of 2,000,000 ac.-ft., half of which will be credited to the State of Victoria. In addition, considerable quantities are drawn direct from the Murray river. On completion of the Hume reservoir and other storages being provided by minor River Murray works, the total capacity of the storages available for the State will amount to 2,367,570 ac.-ft. The storages in New South Wales, existent and projected, are referred to later. The locations of the main irrigation-districts on the Murray river and its tributaries are shown in the accompanying map.

IRRIGATION IN THE STATE OF VICTORIA

The schemes already constructed and under construction provide for supplies of water to thirty-two irrigation-districts. The supply of irrigation-water is mainly drawn from the head-works constructed on the Murray river, and from the Goulbourn and Loddon rivers, which are tributaries of the Murray.

The Goulbourn irrigation-system.—The Goulbourn system comprises chiefly two main channels and a diversion-weir which raises the summer level of the water 45 ft., giving 408 ft. above sea-level. The principal storage-reservoir within the system is Waranga Basin, from which water for irrigation is distributed to a distance of 230 miles. Additional storage is provided by the Eildon reservoir (Plate 10, Fig. 1), which provides also an outlet for State hydro-electric works. An interesting feature of the Eildon reservoir is the dam across the Goulbourn, which is constructed to a height of 140 ft. above the river-bed, with a foundation, in places, 75 ft. below the surface, and an overall length of 3,000 feet. This wall, excepting 700 ft. of mass concrete forming a flood spillway, consists of a rock-fill bank with a reinforced concrete-core wall (Plate 10, Fig. 2).

The main channels of the Goulbourn system have an aggregate length of 340 miles, in addition to which there are 2,300 miles of distributaries and 500 miles of drains, a total of 3,140 miles for the whole system.

The various irrigation-areas of this system total approximately

1,293,500 acres, and produce mainly fodder-plants and irrigated pastures, and also fruits. Among the latter, stone-fruits predominate, the aggregate production of the three co-operative canneries (Shepparton, Ardmona, and Kyabram) being 24 million cans in 1933.

River Murray irrigation-systems.—Several irrigation-works for service of frontage lands on the Murray are in operation between Echuca and the South Australian border. The districts between Echuca and Swan Hill are supplied from the Torrumbarry weir and lock, by means of which the summer level of the Murray river can be raised 16 feet, which is sufficient to permit diversion by gravitation. The districts of Nyah, Red Cliffs, Mildura, and Merbein are supplied by pumping from the Murray river.

The gravitational scheme from the Torrumbarry weir serves 202,500 acres in the Leitchville, Cohuna, Gonnawarra, Koondrook, and Swan Hill districts, and, when supplemented by the Kow Swamp reservoir, about 114,000 acres farther south in the Kerang and Mystic Park districts. The major portion of the land watered wholly by gravitation (excepting Woorinen) is used for fodder-crops and pastures, whilst the settlements supplied by pumping are used almost entirely for fruit-growing.

The main fruit-growing areas comprise Tresco (1,100 acres), Nyah (3,800), Red Cliffs (11,000), Mildura (11,000), and Merbein (8,400). All of these are under the control of the State Rivers and Water Supply Commission, excepting Mildura, which is controlled by the First Mildura Irrigation Trust. The River Murray settlements served by pumping are compact, consisting of small-holdings, usually 15 to 20 acres, which adjoin. The chief products are grapes and citrus fruits, with grapes for drying purposes greatly predominating. The more recent of these settlements (Red Cliffs) is described in detail later.

Loddon-river systems.—This is a gravitational system, used for fodder-crops, the head-waters comprising a regulating weir on the Loddon at Laanecorie, with a capacity of 6,650 ac.-ft. This serves an area of 79,200 acres for domestic and stock purposes and partial irrigation varying in extent from year to year.

Werribee system.—There are two reservoirs, Pyke's Creek (21,000 ac.-ft.) and Melton (17,000 ac.-ft.) in this system. These serve respectively 3,495 and 8,141 acres of land for annual crops and pastures relatively close (25 miles) to the city of Melbourne.

Macallister-river (Maffra) system.—The head-works of this system comprise a storage-reservoir of the Macallister river at Glenmaggie in south-eastern Victoria. The ultimate storage-capacity is designed at 150,000 ac.-ft., commanding by gravitation some 80,000 acres of rich flats on the Macallister, Ovens, and Thomson rivers. The area first supplied was 8,000 acres, and was constituted the Maffra Irrigation District in 1927. More recently, extensions have been made in the Sale district, and the total irrigable area of the Maffra-Sale district is now about 41,900 acres, of which some 20,000 acres are being irrigated. The chief products of the district are sugar (from beet), butter, and condensed milk, for which factories have been established.

The Irrigation-Settlement of Red Cliffs

(i) *General.*—The settlement at Red Cliffs is hereunder described in special detail, as an example of the intensification of industry and population achieved by the application of irrigation-water to lands of low rainfall. Prior to irrigation, the land of the settlement depended on an average rainfall of 10 in. Such land is marginal in respect to wheat-growing; in an unimproved condition it has a carrying capacity of approximately one sheep to ten acres.

(ii) *Irrigation-system and settlement.*—The Red Cliffs irrigation-settlement is situated on the Murray river in north-western Victoria. The settlement comprises a total area of 18,000 acres, of which approximately 11,500 acres are now served with irrigation-water. The land was acquired by the State for the settlement of ex-soldiers, and the scheme of works for the district ranks first in importance among Victoria's pumping-systems. The works include a pumping-plant capable of delivering 500 ac.-ft. of water per day. The water is lifted 105 ft. along a reinforced-concrete rising main, 6½ ft. in diameter and 34 chains long. Thereafter, the water is distributed by gravitation, except at two points where it is necessary to re-lift by relatively small motor-driven pumps. A system of main and distributing channels commands each of some 670 holdings. The length of channelling is now 133 miles, of which all portions adjoining irrigated holdings (114 miles) have been lined with concrete to decrease wastage of water and to preserve soil fertility.

The individual holdings average approximately 17 acres, and are occupied by some 670 settlers under the provisions of the Closer Settlement Act of Victoria. Approximately 500 of the present settlers are repatriated ex-soldiers of the Great War.

The Red Cliffs township is placed centrally and includes the offices of the government departments concerned, fruit-packing houses, and the usual private residential and business premises. The settlement is compact, the holdings being within a three-mile radius of the township, thus giving electric lighting and power facilities to settlers, as well as daily deliveries of household necessities. Approximately 2,750 persons reside permanently in the district, with the addition of about 1,500 migrating workmen who visit the district for a period of about six weeks at harvest.

(iii) *Produce.*—The major plantings in 1934 were, in acres: Vineyards (vines and citrus), 11,133; Lucerne, &c., 400; and Miscellaneous, 112: total, 11,645.

The principal product of the district is dried fruit, the production of which for the past five seasons has varied from 13,000 to 17,000 tons. The sale of dried fruits constitutes the principal source of income for the settlement, supplemented by fresh fruits (grapes and citrus), and annual crops (peas). Poultry, cattle, and pigs are secondary, being limited practically to domestic requirements.

The value of the dried fruits may be computed fairly accurately, since all the fruit goes into a common pool. The annual income of the settlement naturally varies with production and sales. As the dried fruit is pooled,

it has been found possible to compute total returns from the various markets with reasonable accuracy. These may be stated as follows:

Value of Sales of Dried Fruit

	United Kingdom	*Canada New Zealand The East*	*Australia*	*Total*
	£	£	£	£
1931 . . .	364,000	67,000	160,000	591,000
1932 . . .	183,000	214,000	227,000	624,000
1933 . . .	411,000	73,000	119,000	603,000
1934 . . .	248,000	143,000	165,000	556,000

Average annual realization for dried fruits: £593,500.

It is estimated that the settlement-income from dried fruits is supplemented by approximately 7 per cent. of its total from other sources.

(iv) *General finance.*—The settlement was undertaken by the Victorian Government. The main works, channelling, clearing, &c., were constructed immediately after the War, at a time when costs were further raised by the necessity for employing ex-soldiers, who were naturally excluded from experience in such work during the War period. These abnormal conditions have resulted in a capital debt of £780,379 on June 30, 1934, for the Red Cliffs settlement of 11,000 acres, in contrast with a capital debt of £227,972 on the same date for the Merbein settlement of 8,400 acres. A general charge of £3 10*s*. per acre per annum is made for irrigation-water over the whole of the settlement. A portion of the rates collected (approximately 54 per cent. of the total revenue derived from this source) is absorbed in annual costs, the remainder contributing towards the annual interest on expended capital. The irrigation-rate is not sufficiently high to cover the whole interest on the capital expended in addition to annual expenditure.

At June 30, 1934, £481,799 of the total capital indebtedness was allocated to the settlement, the remaining portion being placed in a suspense account, and the interest met from general State revenue. The economic relations of the irrigation-settlement of Red Cliffs to the State of Victoria cannot be accurately computed, as other sources of State revenue, including railway freight and income-tax, are favourably affected.

(v) *Individual finance.*—The majority of the individual settlers had little or no funds when the land was taken up, and were financed mainly by the Victorian Government. Within five or six years, the value of the individual holdings rose very rapidly, up to, say, an average capital value of £2,500 for holdings of 17 acres. The increased value was due to the erection of buildings, plant, and the development of horticultural plants, and represented reproductive expenditure with little unearned increment. Government collections have been satisfactory in that the individual indebtedness to the Government is being steadily decreased, with a consequent increase in the settler's equity. In general, the Government collections from all sources have been calculated to permit a satisfactory

income for the settler, plus a satisfactory increase in his equity in the holding.

(vi) *Production methods.*—The experiences of the adjoining older settlements of Mildura and Merbein, in respect of horticultural and irrigation practice, and especially the organized sale of the principal produce, dried fruit, were of immense value to the settlement of Red Cliffs. In particular, it was found possible to minimize soil wastage and the consequent reduction in capital value hitherto associated with the introduction of irrigation-water to soils of these types. From the inception of the settlement, the lay-out and the method of irrigation were designed to prevent harmful accumulations of the free subsoil water associated with soil wastage. The precautions, with the addition of agricultural drainage where free water has accumulated, are proving successful. At the present time, after fourteen years of occupation, every one of the original holdings is occupied and supporting a family.

The advance of experience in irrigation is such that continued productivity may be anticipated, with improvement in irrigation-distribution, and the installation of community drainage-schemes now in course of construction. The preservation of soil productivity, and the improvement in soils that show signs of wastage, constitute the chief research problems of the district. Horticultural practices, including the processing of the fruit, appear satisfactory in comparison with the methods used in other countries.

The cultivated area under irrigation in Victoria.—The total extent of irrigation and variations for the years 1929–34 are shown in the following table. A detailed statement of all the irrigated areas and of the crops cultivated thereon may be found in the Annual Report of the State Rivers and Water-Supply Commission of Victoria for 1933–4.

	Area under Irrigation (acres)				
Source of Supply	*1929–30*	*1930–1*	*1931–2*	*1932–3*	*1933–4*
Goulburn State Works	322,039	242,435	212,284	243,378	217,105
River Murray State Works	173,642	156,169	136,254	158,223	151,714
Loddon and other Northern State Works	12,486	12,067	11,120	11,621	14,496
Southern State Works	25,831	22,662	28,094	31,042	23,687
Mildura and Private Diversions	32,579	29,765	30,663	30,452	28,322
Totals	566,577	463,098	418,415	474,716	435,324

IRRIGATION IN THE STATES OF AUSTRALIA (*Other than Victoria*)

For comparison with the irrigated areas in the State of Victoria, the extent of irrigation in New South Wales and South Australia, and the crops grown there, are briefly discussed. Irrigation in Western Australia and Queensland are relatively unimportant. Queensland irrigates about 22,000 acres for market-garden and other crops, and 4,000 acres of orchards and vineyards. Western Australia has about 2,500 acres of irrigated fodder and market-gardens with approximately a similar acreage for fruit-production.

New South Wales.—The Murrumbidgee irrigation areas are first in importance. The water is supplied by gravitation from the Burrinjuck reservoir, which is situated in the upper reaches of the Murrumbidgee river. The capacity of the storage is 771,640 ac.-ft. at full-supply level, and in 1934–5 irrigation water from this reservoir served 87,374 acres of land in the Murrumbidgee area for the following crops:

Crops	*Acres*	*Tree-fruits*	*Acres*
Oats	8,996	Citrus	5,640
Wheat	16,077	Vines	5,477
Maize	99	Deciduous, &c.	6,213
Barley	233	*Miscellaneous*	
Lucerne	3,356		
Millet and grasses	7,283	Vegetables	1,668
Rice	20,411	Tobacco	16
Pastures	2,674	Other sundries	63
		Fallow, &c.	9,168
Total	59,129	Total	28,245

In addition to the Murrumbidgee irrigation area, there are three irrigation areas controlled by the State. Two of these, Curlwaa (2,208 acres) and Coomealla (2,106 acres), are fruit-growing settlements near Mildura on the north side of the River Murray, from which the irrigation-water is obtained by pumping. The Hay settlement (1,040 irrigable acres) is on the Murrumbidgee river, and the water is used principally for fodder-crops. There are also several irrigation districts controlled by private irrigation-trusts. Two of these, Goodnight (1,364 acres) and Koraleigh (1,785 acres), are fruit-growing settlements on the Murray river near Nyah; there is one fruit-growing settlement, Pomona (1,224 acres), near Wentworth, on the Darling river, and a number of relatively small areas, chiefly on the Murray, which supply irrigation-water for fodder-crops.

Great extensions in irrigation in New South Wales are projected. During the year 1935 the work of constructing a supply-channel to the Berriquin district was started. This supply-channel (the Mulwala canal) leads from the site of a projected weir at Yarrawonga, on the Murray, to the Berrigan district, the main channel being 96 miles in length and 125 ft. wide at the bottom. Channels of total length of 500 miles are also projected. These works are designed to supply water for domestic and stock purposes, a limited amount for irrigating some of the large holdings covering a total area of 618,000 acres, with an ultimate extension to an additional area elsewhere.

A somewhat similar scheme is planned for the Wakool district, supplying an area of 540,000 acres. As the supply of water at Albury, as regulated by the Hume storage, will be shared equally by New South Wales and Victoria, subject to reserved supplies for South Australia, very considerable extensions of irrigation in the Berrigan and Wakool districts may be anticipated.

South Australia.—The South Australian irrigation-settlements are of two types: fruit-growing settlements, which obtain irrigation-water by pumping direct from the Murray river, and low-lying flood-plains near the mouth of the Murray, protected by levee-banks, and used

FIG. 1. Eildon Reservoir. General view of bank during remedial work 1929–30. From lower slopes of Mt. Pinniger

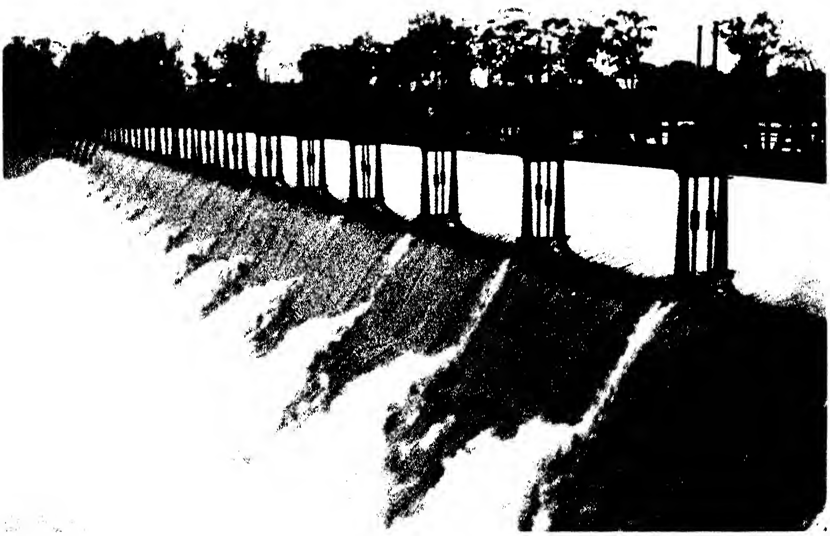
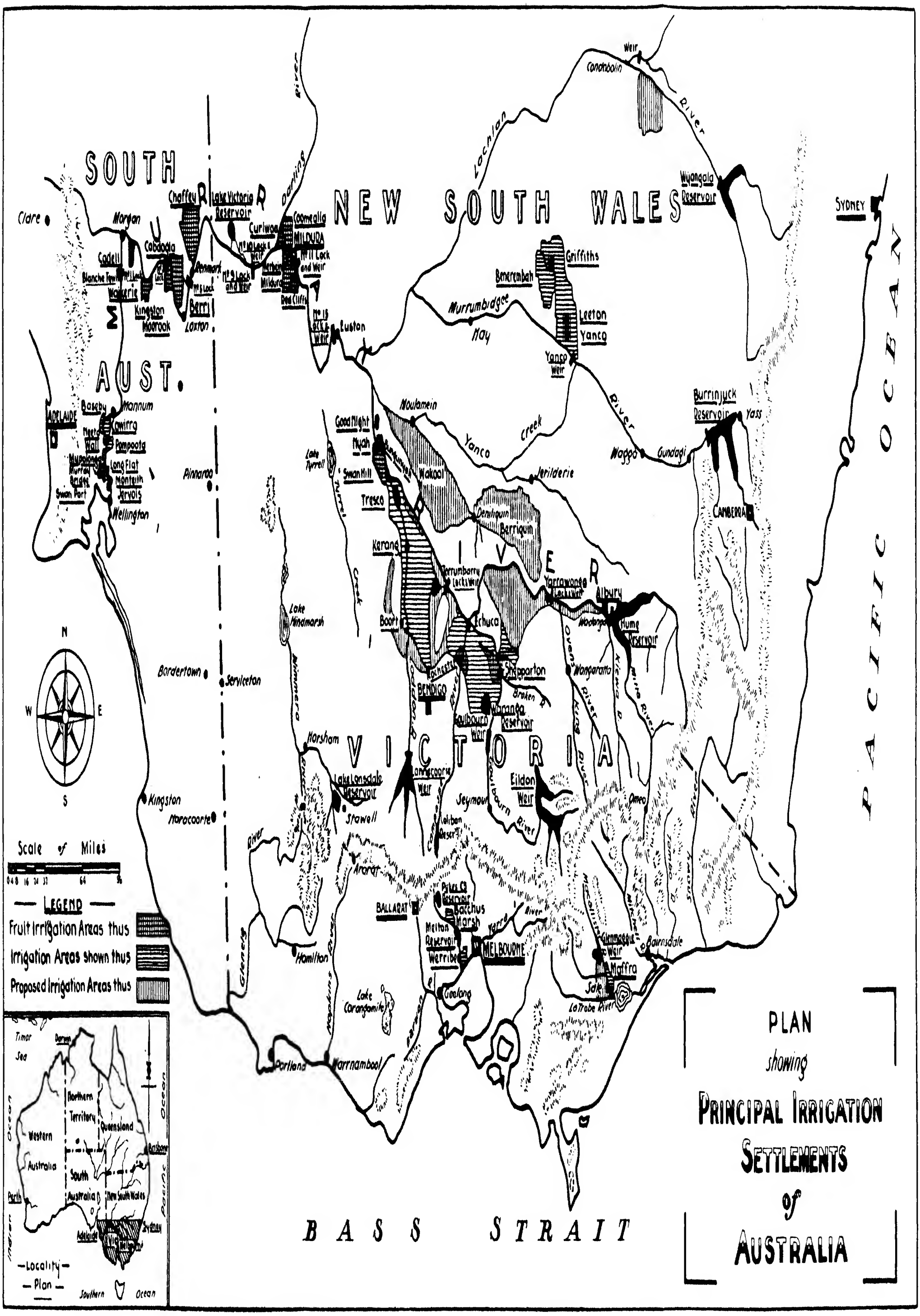


FIG. 2. Goulbourn Weir, Victoria



PLAN
showing
PRINCIPAL IRRIGATION
SETTLEMENTS
of
AUSTRALIA
SOUTH AUST.
NEW SOUTH WALES
VICTORIA
RIVER MURRAY
PACIFIC OCEAN
BASS STRAIT
SYDNEY
CANBERRA
MELBOURNE
ADELAIDE
BALLARAT
BENDIGO
Mildura
Griffiths
Leeton
Yanco
Wyangala Reservoir
Burrinjuck Reservoir
Hume Reservoir
Eildon Weir
Lake Victoria Reservoir
Scale of Miles
LEGEND
Fruit Irrigation Areas thus
Irrigation Areas shown thus
Proposed Irrigation Areas thus
Locality Plan

for fodder-crops. There is a group of six irrigation-settlements producing fruit within a distance of about 35 miles on the Murray river. These comprise Renmark (9,000 acres), Berri (7,416), Cobdogla (4,104), Moorook (614), Kingston (502), and Lyrup (500 approx.).

The Renmark settlements are controlled by local trusts, whilst the remaining four settlements in this group are administered by the South Australian Department of Lands. There are three other fruit-producing settlements of similar type on the Murray river in South Australia, Waikerie (3,282), Cadell (1,000), and Mypolonga (855). Approximately 73 per cent. of these irrigated lands are planted with vines, 21 per cent. with orchards, principally citrus, and 6 per cent. with fodder-crops.

The irrigated lands on the lower Murray are distinct from other irrigated lands in Australia. They are situated near the mouth of the Murray, for a distance of about 50 miles from Wellington, at the mouth, to Mannum. The irrigated areas comprise swamps reclaimed from the Murray by levee-banks close to the main stream, pumps, and a drainage-system to reduce the level of the water-table to a depth of about 30 in. Irrigation-water is obtained direct from the Murray by sluice-gates in the levee-bank, or by a syphon initially operated by a small pump and engine.

Dairying is the main industry, the major plantings being lucerne and other fodders. Approximately 13,000 acres have been reclaimed by the drainage-system, in areas ranging from 60 to 3,800 acres, and are in various stages of development. At the time of writing, 7,167 acres of these swamp-lands are planted, 2,238 acres of which are under lucerne and 4,929 acres under fodder-crops, with a growing tendency to develop permanent pastures. The planted areas carry 6,500 head of cattle, of which approximately two-thirds are milking-cows.

Conclusion.—Brief reference only has been made to production methods and soil type. Systematic soil surveys are relatively recent in Australia, and the present position of this work is given in publications of the Australian Council for Scientific and Industrial Research.

Although development of additional irrigation-areas is still in progress, there has been in recent years a growing tendency to improve irrigation-methods, particularly with a view to avoid soil wastage, so manifest in the early settlements. There is evidence that, in districts where irrigation methods are being modified as a result of research, there has been considerable success in maintaining and improving the fertility of the irrigated land.

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FISH-POISON PLANTS AS INSECTICIDES

A REVIEW OF RECENT WORK

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Introduction

In recent years widespread attention has been given to the control of insect pests by chemical means. The literature on the subject has already grown to very large dimensions and covers fields of great extent and variety. Mineral products, such as the arsenicals and fluorine derivatives, synthetic organic derivatives, products of the oil and coal-tar industries as well as many plants, have been used as insect poisons and deterrents, and in addition much attention has been given to the preparation of adjuvants and to the physical and mechanical factors leading to more effective application of insecticides.

The search for plants having insecticidal properties, and the production of the more potent of these on a large scale, have not been the least important phases of the work. The main object has been to discover and, if possible, cultivate plants which, whilst containing poisons highly potent to insects, are relatively harmless to man. Although this ideal objective has not been completely realized, a large measure of success has been attained. Most of these plant products belong to the group of insecticides known as contact insecticides, which on being brought into external contact with the organism either penetrate the chitin or find access to some vulnerable part via the tracheal system, although there is evidence to show that some of them, e.g. nicotine and rotenone, may act as stomach poisons, and kill by ingestion. Recent research has been chiefly devoted to three classes of these plants:

1. Certain leguminous plants used by natives of tropical countries for stupefying fish.
2. Pyrethrum.
3. Plants containing alkaloids of the nicotine class, e.g. anabasine.

This article deals with the first-named class.

Fish-Poison Plants[1]

Whereas many natural orders of plants are used as fish poisons, only those of the order *Leguminosae* have so far proved of importance as insecticides, although *Cocculus indicus* (Menispermaciae) containing a neutral active principle 'picrotoxin' has some reputation as a parasiticide, and it has been reported that the bark *Barringtonia racemosa* has insecticidal properties. By far the most important groups from this point of view are the leguminous plants which contain active principles closely

[1] A valuable account of these plants with an excellent bibliography is given by F. N. Howes (*Kew Bull.* (1930), No. 4, p. 129). Roark has published a very full digest of the literature of *Derris* (*Deguelia*) species used as insecticides 1747–1931 (U.S. Dept. Agric. Misc. Pub., No. 120, 1932).

related in structure to each other, of which rotenone is the most important. Many of these plants are exceedingly potent insecticides. They occur mainly within a tropical and semi-tropical belt and are widely distributed. The chief among them are species of *Derris* (*Deguelia*), *Lonchocarpus*, and *Tephrosia* (*Cracca*). Each of these genera contains species having little or no insecticidal properties, and there appears to be a wide range of activity for each of the species and varieties known to be toxic. It seems highly probable that only the more potent plants will find a ready market in Europe and America, although this conclusion may require qualification in cases where the material is to be used for dusting, and when the price of the poor-quality material more than counterbalances the cost of inert diluents used with high-quality material.

Nomenclature.—It appears to the writer that the use of local native names for these plants in the past has proved a darkening of counsel, and the recent work of M. R. Henderson [1], in which he attempts to distinguish the different kinds of derris in the field by leaf characters and habit of growth, is timely. It is hoped that it will be expanded for *Derris* and other genera in order to enable us to ascertain whether the chemical characteristics and insecticidal potencies are associated with particular varieties, and whether and to what extent they are dependent upon environmental conditions of soil and climate. Before this can be adequately carried out some means of chemically evaluating these roots, more reliable than those we now have, would appear to be necessary.

Active principles.—Several crystalline products of different degrees of insecticidal activity have been isolated from these plants and their structure ascertained by the labours of teams of workers in different parts of the world. They are rotenone, deguelin, toxicarol, the tephrosins, and a new compound isolated by Cahn and Boam [2]. Of these rotenone is so much the most active that for some time it was thought that its determination would be sufficient to ascertain the relative potencies of these plants and, as it was more easy to isolate it than the other constituents, a ready and rapid method of evaluation seemed to be in sight. This hope, however, has receded during the last two years. It is now pretty clear that deguelin, toxicarol, and tephrosin do not exist in derris and cubé root in the form in which they are isolated. Takei and his co workers [3] have by a simple oxidation process converted deguelin into tephrosin and *iso*tephrosin. The isolation of deguelin and toxicarol from *Derris* and *Lonchocarpus* spp. as well as from *T. toxicaria* has usually been accomplished by the use of alkali. Clark [4], who first isolated deguelin and determined its structure, considered that it was in some form of combination, but an alternative view is that at least part of the deguelin is present in an optically active form, and that since the deguelin so far isolated in a pure state has shown no optical rotation, racemization caused by the process of extraction has lowered its insecticidal power. F. B. LaForge and H. L. Haller, who in association with L. E. Smith first published the chemical structure of rotenone [5], universally accepted to-day, have prepared [6] what they term a 'deguelin concentrate' from which dihydro-deguelin was isolated after hydrogenation. Campbell and Fink found this active compound more toxic than inactive dihydro-

deguelin when used against mosquito larvae. It is thus at least probable that the relatively feeble toxicities found for deguelin (and possibly toxicarol), as isolated, are not a measure of the toxic properties of their precursors in the root.

There is a great deal of converging evidence demonstrating that rotenone is not wholly responsible for the toxicity of derris and cubé. It has been shown by Jones *et al.* that a derris extract from which only 25 per cent. of rotenone could be isolated was as toxic to mosquito larvae as pure rotenone. Campbell and his collaborators [7] found deguelin to be nearly as effective against house-flies as rotenone, and that a kerosene extract of a sample of derris from which no rotenone could be isolated was also effective against this insect. Fryer *et al.* [8] found the resins, freed as far as possible from rotenone, toxic to insects. Many other observations of the same nature have been made. There is, however, the possibility that the amount of rotenone separated by present methods from the resins does not represent the whole amount in the root. Cahn and Boam [9] have shown that the so-called Sumatra-type roots, from which no rotenone is obtainable by the Jones method[1] [10] may yet contain up to 2·4 per cent. of rotenone in a 'hidden' condition, and that the standard method of determination may be seriously in error if the extracted resins contain less than 10 per cent. of rotenone. The work of Takei and his co-workers [3] also indicates that crystallization from an ether solution of the resins does not yield the whole of the rotenone present. It is therefore possible that some part of the insecticidal activities of the uncrystallizable resin may be due to rotenone in this 'hidden' state, but the evidence at present available shows that one or more highly toxic substances, one of which may be optically active deguelin, play an important part. Cahn and Boam's conclusion [2] 'that the value of derris root or resin can only be assessed by its rotenone-content is quite unjustified' is borne out by all the recent work.

Chemical evaluation.—In two recent papers by Jones, Campbell, and Sullivan [11] and Tattersfield and Martin [12] the problem of the chemical evaluation of these plants is examined in some detail, and although neither paper proposes what can be regarded as a final solution of this difficult problem, suggestions are made which may be of value towards that end. The chief value of these papers is perhaps to be found in the presentation of two different criteria by means of which the validity of a chemical method can be determined. There is substantial agreement between them that the percentage amount of rotenone, as at present determined, the total extractives in benzene or ether, and the methoxyl-content of the total benzene or ether extract cannot be correlated with the activity of all the samples examined by these workers. The American investigators found that for a number of their samples, but with marked exceptions, the estimation of rotenone and deguelin by the Gross and Smith test [13] showed a fair agreement with toxicity, and Tattersfield and Martin found that an estimation of the dehydro compounds (mainly

[1] This method of estimating rotenone has been modified by C. D. V. Georgi and G. L. Teik (Bull. Dept. Agric. Straits Settlements and F.M.S. Sci. Series, 1933, No. 12), and by Cahn and Boam (loc. cit.).

rotenone and deguelin) by Takei's method gave a relatively good comparative assessment of the insecticidal power of a more limited number of samples of derris root. Jones, Campbell, and Sullivan found a sample of a type, termed by Cahn the Sumatra-type derris root, exceptional, and recent (unpublished) work by the writer and Dr. Martin has indicated that the determination of the dehydro compounds by Takei's method in the case of a similar sample gave an erroneous estimate of its toxicity. Jones, Campbell, and Sullivan found that the estimation of a value termed 'rotenone based on the methoxyl-content minus toxicarol' gave, with one or two exceptions, a fairly close correlation with the potency of the root. It has, however, not been found by the author that the alkali-extractable material of derris resin has in all cases a methoxyl-content of the same order as toxicarol, and the part played by this compound in the insecticidal properties of derris and cubé roots is at present obscure. The necessity for studying roots of different types and the resins obtained from them in greater detail is clear. It would, moreover, seem to be important that the biological data should be subject to statistical analysis; the recent work of C. I. Bliss [14] on the comparison of dosage-mortality data may prove a useful instrument for testing the validity of any chemical method of evaluating these plants.

Effect of genetical and environmental factors.—To ask what part these compounds play in the economy of the plant, or by what metabolic process they arise, is not likely to elicit any answer of value for a considerable time. But the query, whether the relative amounts of the active principles, particularly the proportion of rotenone to uncrystallizable resin, are determined by genetical factors, or can be altered by environmental conditions of soil, manuring, and climate, are important. Georgi and Teik [15] and several observers have noted a higher proportion of rotenone to ether extractives in the case of *D. elliptica* than of *D. malaccensis*, but certain analyses of the latter variety, grown on the Belgian Congo [16], showed a high proportion of rotenone to ether extract. The question therefore arises whether a rough demarcation of these species can be made by chemical means. The number of varieties and sub-varieties of both *D. elliptica* and *D. malaccensis*, as given by Henderson [1], render the problem a difficult one. It is not made any easier by the fact that a sample of wild roots, vouched for as *D. elliptica*, was found at Rothamsted to have no rotenone, a low ether-extract, and no toxicity to insects. The question whether any of these varieties are capable of showing under one set of cultural conditions results given by the Sumatra type, and under another a high rotenone-content, is one of no little importance. That these plants are leguminous should not be lost sight of, and specific root-nodule-forming bacteria may play some part in their economy. Weber [17] found that lupin plants bearing nodules had a higher alkaloid-content than those without them, and although the elaboration of a non-nitrogenous compound of the type of rotenone may not be comparable with that of the nitrogenous alkaloids, the matter may be worth inquiry, as may also be the critical study of the effect of manures and the effect of the presence or absence of traces of such

elements as boron, which is known to have an important effect upon the growth of many plants of this order.

Koolhaas [18] reports that 32 samples of derris from the Dutch East Indies ranged in rotenone-content from 0·3 to 10·9 per cent., and the selection of roots of high rotenone-content for planting in the Dutch East Indies is being made. There are also reports of the planting of derris in the Philippines, where a number of species and varieties are found ranging in rotenone-content from 0·02 to 1·68 per cent. The experimental cultivations of certain varieties of *D. elliptica* and *D. malaccensis* on the Belgian Congo [16] and of *D. elliptica* on the Gold Coast have been successful. Samples of the latter submitted to the Rothamsted Experimental Station contained 2·5 and 2·8 per cent. of rotenone. It is obvious that the cultivation of *Derris* can be undertaken over a large area. Whatever method for evaluating these plants is finally elaborated, there would appear to be no doubt of the sales value of a high content of rotenone, particularly if it is to be coupled with high ether-extract.

Cubé, Haiari, and Timbó.—Much work seems to have been done in Peru in the cultivation of cubé or barbasco (*Lonchocarpus nicou*), and Brazil is becoming increasingly interested in timbó, a species of *Lonchocarpus*. Roark [19], in discussing the relative merits of derris and cubé, considers it as well established that, for a given rotenone-content, derris contains, in general, larger quantities of ether extractives than does cubé, and since these extractives are toxic, in general, derris will be more toxic. Jones, Campbell, and Sullivan [11] obtained rather variable results for some samples of equivalent rotenone and total-extract contents. For one pair of samples toxicity was about equal, whilst for another cubé proved slightly less toxic than derris. They consider that no general conclusions can be drawn from their data. Some samples of cubé and timbó have been found with very high rotenone-content, occasional specimens of the former containing as much as 12 per cent. rotenone and of the latter one as high as 15–16 per cent. have been reported, but these are exceptional. Commercial samples of cubé examined at Rothamsted have usually ranged from 5–6 per cent. and good samples of *Derris elliptica* have touched 8–9 per cent. There is, however, little or no question that these South American plants are being produced in continually increasing amounts and that in course of time competition with derris is likely to be severe.

It has been recently established that the White Haiari of British Guiana is *Lonchocarpus nicou* (Aubl.) D.C. and conspecific with cubé of Peru; thus there are obviously several strains of this plant which differ somewhat widely in rotenone-content. Haiari plants taken from forests of British Guiana, and from their appearance of many years' growth, analysed at Rothamsted, showed appreciable amounts of rotenone. Black Haiari roots contained over 3 per cent. and the stems about 0·8 per cent. White Haiari roots gave 1·8 and the stems 0·6 per cent. of crude rotenone by the carbon tetrachloride method. Cultivated specimens, six years old, of Black Haiari gave 1·4 per cent. and of White Haiari 0·9 per cent. rotenone, the stems in both cases containing only traces. A further search for other and richer strains of *Lonchocarpus* in that colony would

appear to be worth while. There is always the possibility, as Killip and Smith [20] point out, that in Peru the cubé plant, cultivated for centuries as a fish-poison, may represent a selected strain in which the content of toxic principles of the roots is at a maximum.

Tephrosia species.—Of the species of *Tephrosia* (*Cracca*) the most important are *T. macropoda*, *T. toxicaria*, *T. virginiana*, and *T. vogelii*. The first-named, a plant deriving from Natal, has been reported by Tattersfield and Gimingham [21] as possessing insecticidal properties, and recent (unpublished) work at Rothamsted has shown it to contain rotenone (0·3–0·4 per cent.), and other derivatives of an insecticidal nature are undoubtedly present. *T. toxicaria* appears to be widely distributed over the more tropical parts of South America. A sample of the roots tested at Rothamsted proved to have insecticidal properties [22]. The yellow crystalline compound isolated from it was named toxicarol by Clark [23]. Its toxicity to insects is not due to this compound as isolated. *T. virginiana* and *T. latidens* are of interest as being North American plants, showing both the properties of poisoning fish and insects. The insecticidal properties of the roots of *T. virginiana* were pointed out by Little [24]. Jones, Campbell, and Sullivan [25] have published a valuable report of the chemical composition and insecticidal value of the species of *Tephrosia* (*Cracca*) occurring in the United States. In the two species mentioned they have found rotenone present to the extent of 0·2 to 0·5 per cent. It is interesting that the most effective samples of *T. virginiana* came from Texas; samples from other sources were not so effective. *T. vogelii* is of considerable interest, as its leaves and seeds contain the active principles. Only one other fish-poison plant, said to be a species of *Derris* from the British Solomon Islands, and sent to Rothamsted by Mr. H. T. Pagden, has in the experience of the author possessed leaves with insecticidal properties.[1] It is obvious that such leaves and seeds could be more readily harvested than roots. In potency, however, the *Tephrosia* species are hardly in the same class as the richer roots of *Derris* and *Lonchocarpus* spp., but that they might be improved by selection and hybridization should not be lost sight of. Worsley [26] has confirmed and extended the earlier observations of Tattersfield, Gimingham, and Morris [22] on the insecticidal properties of *T. vogelii*. He finds that as a contact insecticide against aphis, thrips, and similar soft-bodied insects, extracts of *T. vogelii* are effective, and considers that it might displace nicotine for use against these insects in East Africa. He has noted its effectiveness in the form of paraffin extracts against flies and mosquitoes, if directly hit by the spray. Wilbaux [27] has found that, in addition to their insecticidal properties, extracts of *T. vogelii* are bactericidal. The plant is widely spread on the African continent and, like the other species of this genus and such other legumes as *Neorautanenia fisifolia* and *Mundulea suberosa*, may find a local use.

Chemical structure.—Of the crystalline derivatives isolated from fish-poison plants, structural formulae have been ascribed to rotenone and deguelin and tephrosin. A summary of much of the work upon the chemical structure of rotenone is given by LaForge, Haller, and Smith

[1] Jones *et al.* (loc. cit.) found the seeds of *T.* (*Cracca*) *lindheimeri* effective.

[5] and by Takei [28]. The structures given by Clark to deguelin and tephrosin are now generally accepted [29]. In the case of tephrosin there appears to exist a complicated isomerism [30]. The structure of toxicarol has been the most difficult of these compounds to unravel, but recently Heyes and Robertson [31] have suggested two alternative formulae to account for its reactions. In view of the fact that rotenone contains three asymmetric carbon atoms, and that its insecticidal potency probably depends in some obscure way upon its particular molecular orientation, it appears at present unlikely that it will be synthesized so as to be able to compete in price with the natural product.

Toxicity to insects.—A body of knowledge is gradually being built up of the insecticidal usefulness of these plants, particularly of cubé and derris. Kelsall and his collaborators [32] have given a series of interesting notes on the toxicity of derris to various species of insects. Roark [19] gives also a list of insect pests in America, controlled by it, and mentions that during 1933, 300,000 lb. of ready-prepared derris dusts were sold on Long Island as substitutes for arsenicals. Much work has been done on the control by derris of caterpillar pests on *Cruciferae*. Campbell [33] has also reported tests on fifty-five species of insects. De Bussy, van der Laan, and Jacobi [34] have published results of the control value of derris powder and rotenone on Netherlands insects. For the control of Warble-fly the observations of Wells, Bishopp, and Laake [35], of McDougall [36], and of Gaut and Walton [37] have been confirmed by later experimenters, as have those of Steer [38] on the control of *Byturus tomentosus* on Raspberry and Loganberry. Bishopp and his co-workers [39] have given accounts of the control of various animal-infesting pests, and Crane [40] has tested the utility of rotenone against a number of internal parasites of dogs. Buckingham [41] claims rotenone to be non-toxic to warm-blooded animals administered *per os* and Crane (loc. cit.) found it non-toxic to dogs up to 0·2 gm. per 1 kg. body-weight. Such internal usages should be carried out with care, as this compound has been known to give rise to intestinal irritation and death in mice in some experiments carried out at Rothamsted. Several patents have been taken out for its use as sheep-dip and vermifuge.

Physiological action.—The active principles of these plants are usually slow in their paralysing and lethal effect upon insects, in marked contradistinction to the pyrethrins, but it has been noted that rarely does an insect recover from the narcotic effects if they are at all deep. Often the effects of the pyrethrins are fugitive. and it would appear as if these two insecticides might supplement each other's action. It is interesting to note that patents covering such mixtures have been taken out in the United States of America.

The physiological action that derris and its active principles have upon insects is as yet not exactly known, but Miller [42] considers that its supposed action as a stomach poison needs re-investigation. Miller's paper contains an interesting report by Dr. Buckley of an analysis of the excreta of the cockroach *Periplaneta americana* L. after being fed upon, but apparently not seriously affected by, a diet containing rotenone. The conclusion was drawn that these cockroaches, though excreting a certain amount of

rotenone unchanged, were able to build up a derivative insoluble in carbon tetrachloride, but capable of yielding rotenone again on treatment with sulphuric acid. The total rotenone consumed was far more than that recovered from the excreta, thus indicating some nutritive function.

Loss of activity.—Like pyrethrum, derris and cubé lose their activity under certain conditions. Spoon [43] concludes that they will keep for reasonable periods if properly stored, but there is little doubt that sprays made with soap solutions do deteriorate after a time. However, Miller (loc. cit.) regards the loss of activity to be less rapid than it is generally considered to be. Durham observed a change in rotenone on exposure to light. Tattersfield and Roach [44] noted the formation of yellow-coloured derivatives when rotenone solutions were exposed to sunlight and ultra-violet light. A detailed study of the detoxication of rotenone in light has been made by Jones, Campbell, and their co-workers [45], and it was concluded that the loss was sufficiently rapid to limit its use as a stomach poison but probably not as a contact poison. So far, no really adequate means has been discovered for overcoming this drawback. The drawback, however, is only a partial one, and although it may account for the failure to control codling moth, there is a countervailing advantage that when used on market-garden crops the spray residue left, unlike the arsenicals, causes apparently no anxiety from the point of view of public health.

Some insects are immune to the effects of derris and cubé, certain boring beetles, indeed, constituting a major pest of these products in store; nevertheless, as knowledge of their range of usefulness grows, there seems to be an expanding market for them in both Europe and America for some years to come.

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THE EFFECTS OF PARTIAL FIELD-DRYING ON THE COMPOSITION OF FRESHLY CUT GRASS

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Introduction.—The costs of conserving grass by artificial drying depend very much upon the ratio of water to dry matter (technically termed the 'water ratio' of the grass) present in the grass fed to the drier. It is the more general practice to feed the grass to the drier immediately or shortly after cutting, to avoid possible losses and changes by respiration and fermentation, but it is obvious that some preliminary removal of water by partial drying in the field would considerably improve efficiency by reducing carting and drying costs and by increasing the output of the drier.

The object of this investigation was to gain information on the amount of water removed from freshly cut grass by preliminary drying in the field under natural conditions for periods up to 54 hours, and on the actual extent of the losses and changes occurring in the contents of dry matter, nitrogen, and carotene. The results presented were obtained undei one particular set of climatic conditions, which proved to be favourable for field-drying. Since climatic conditions must obviously play a major part in determining the effects of field-drying in any particular instance, the results cannot be taken as being necessarily applicable to other climatic conditions without further investigation.

A preliminary investigation carried out by S. J. Watson at this Station on October 21, 1931, had shown that drying freshly cut grass in the field for six hours reduced the moisture-content from 81 to 74 per cent. in fine, calm weather (unpublished data); otherwise, no data would appear to be available concerning the preliminary drying of grass for subsequent artificial drying under British conditions. Preliminary field-drying of lucerne, before artificially drying, however, is practised successfully in Germany and in the United States of America.

Outline of Investigation.—The investigation was carried out between May 22 and 24, 1935, on pasture grass, 6 to 8 in. high, which was being cut at the time for artificial drying. The herbage consisted largely of perennial rye-grass (34 per cent.) and meadow foxtail (35 per cent.), with some of the former and much of the latter in flower. The yield was about 19 cwt. dry matter per acre, with a crude-protein content of about 16 per cent. The grass was cut between 9 and 10.30 a.m. on May 22 by a horse-drawn mower with a 40-in. cutting knife, and three different methods of field-drying were employed:

(i) in swaths as cut;
(ii) in windrows consisting of 4 swaths raked together;
(iii) in heaps consisting of 100 lb. fresh grass.

These treatments were replicated three times in random blocks.

Randomized samples of the herbage were examined initially on cutting, and at intervals of 6, 9, 24, 30, 48, and 54 hours thereafter from the

swaths and windrows, and of 6, 24, 30, and 54 hours from the heaps. No material was raked over or disturbed in any way during the field-drying period. The samples were taken in the following manner:[1]

(i) From the swaths. The whole of the herbage from a measured strip of 2 ft. along the swath and extending over four adjacent swaths was collected and weighed. The percentage of dry matter in the herbage was determined by oven-drying duplicate sub-samples of 200 gm. each.

(ii) From the windrows. The whole of the herbage from a measured strip of 2 ft. along the windrow was collected, weighed, and its percentage of dry matter determined as in (i).

(iii) From the heaps. The whole heap was weighed, thoroughly mixed, and duplicate samples taken for determining the percentage of dry matter as in (i) and (ii).

Determinations were made, on individual samples, of total nitrogen, and, on weighted composite samples, of 'Stützer' (or 'true protein') and pepsin-digestible nitrogen. Determinations of carotene were made on composite samples of the fresh grass.

Climatic Conditions.—The daily meteorological readings for the period May 21 to 24 are given in Table 1. The 24 hours prior to cutting were fine, and the grass when cut held a little external moisture from a light dew. During the period of the test no rain fell, and a moderately strong and drying wind from between NE. and E. prevailed the whole time. May 22 was a cool day with considerable sunny periods, May 23 was appreciably warmer and mainly sunny, and May 24 was slightly warmer still but mainly cloudy.

In brief, the weather conditions were conducive to efficient drying, and probably also to minimum losses and changes by respiration and fermentation.

TABLE 1. *Meteorological Readings during Field-drying*

Date	*Barometer*	*Relative humidity*	*Screen Temperature*		*Sunshine hours*
			Max.	*Min.*	
	in.	Per cent.	°F.	°F.	
May 21 .	29·98	73	57	39	10·9
May 22 .	30·05	60	54	36	5·9
May 23 .	29·77	72	64	40	9·4
May 24 .	29·83	67	66	48	2·8

Effects of Preliminary Drying on the Water and Dry-matter Contents of the Grass

(*a*) *Yield of dry matter.*—Although preliminary drying will normally result mainly in loss of water from the grass, some loss of dry matter may also occur under certain conditions, and this, if appreciable, might

[1] (*a*) Adequate precautions were taken to prevent side and edge effects in the swath and windrow methods of drying.
(*b*) Growth-area corresponding to samples taken from both swaths and windrows was accordingly 2 ft. × 3 ft. 4 in. multiplied by 4, or 26·7 sq. ft.

offset, to some extent at least, the advantages obtained in loss of water. In this test, however, as will be seen from the figures for average yield of dry matter given in Table 2, no significant loss of dry matter occurred in any of the methods of drying,[1] so that the losses observed may be taken to be wholly water losses. Though no heating was observed in any of the treatments at any time during the test, it is considered very probable that heating, with a loss of dry matter, might be expected to occur in the windrows and heaps at least, under the warmer weather conditions such as are not infrequently experienced during the grass-drying season.

TABLE 2. *Average Yields of Dry Matter (lb. per sample area)*

Method of Drying	*Period of Drying (hours)* 0	6	9	24	30	48	54	*Standard Error*	*Significant Difference**
Swaths	1·29	1·33	1·29	1·47	1·06	1·06	1·17	0·142	0·44
Windrows	1·32	1·21	1·29	1·27	1·31	1·21	1·12	0·073	0·22
Heaps	22·8	23·1	..	25·3	22·7	..	21·5	0·568	1·9

* P=0·05

(*b*) *Percentage of dry matter in grass.*—The average values for the percentage of dry matter in the grass at the various stages of drying are given in Table 3. Drying effected a significant increase in the percentage of dry matter in the grass up to the 30-hours period for the swaths, 48 hours for the windrows, and 24 hours for the heaps, but beyond these periods no, or little, further loss of water occurred. The rate and degree of drying was greatest in the swaths and least in the heaps, which under the weather conditions obtaining was to be expected.

TABLE 3. *Average Percentage of Dry Matter in Grass*

Method of Drying	*Period of Drying (hours)* 0*	6	9	24	30	48	54	*Standard Error*	*Significant Difference*
Swaths	26·3	30·7	31·0	35·7	46·1	51·6	50·8	1·929	5·9
Windrows	24·4	26·9	28·1	31·4	34·2	42·5	42·3	1·496	4·6
Heaps	22·8	25·2	..	29·6	28·6	..	31·9	0·731	2·4

* The initial differences among the swaths, windrows, and heaps were due to a small but differential amount of drying which occurred during the period necessarily required to complete the cutting of the grass, the formation of the windrows and heaps, and the allocation of the sample areas, before the initial samples could be taken.

(*c*) *Water ratio.*—Of major economic importance in the artificial drying of grass is the amount of water to be evaporated per unit of dry matter present (the water ratio). The significance and importance of this ratio may, perhaps, best be appreciated from the following illustrative figures:

Water-content per cent.	80	75	67	60	50
Dry-matter content per cent.	20	25	33	40	50
Water ratio	4	3	2	1·5	1

Thus the comparatively small reduction of the *percentage* water-content from 80 to 67 per cent. doubles the output of dry matter per unit of

[1] The increase observed for heaps at the 24-hours period would seem to be due to some coincidence and not a real effect.

water evaporated, whilst the further reduction to 50 per cent. moisture increases the output fourfold.

Accordingly, the application of the present results to the artificial drying of grass may be more fully seen from Table 4, in which the figures for percentage dry matter (Table 3) are expressed as water ratios. These figures well illustrate the economic advantages to be derived from preliminary partial drying of the grass in the field.

TABLE 4. *Average Values for Water Ratio*

Method of Drying	*Period of Drying (hours)*						
	0	*6*	*9*	*24*	*30*	*48*	*54*
Swaths .	2·80	2·26	2·23	1·80	1·17	0·95	0·97
Windrows .	3·09	2·72	2·56	2·18	1·92	1·35	1·36
Heaps .	3·39	2·97	. .	2·38	2·51	. .	2·13

(*d*) *Variability of drying.*—The figures so far given for the percentages of dry matter in the grass are, of course, average values for the whole of the material in the swath, windrow, or heap at the time the sample was taken. Actually, the material, except initially, had by no means a uniform dry-matter content throughout, the grass of the outer exposed layers, of course, drying more rapidly than that of the inner less exposed layers. In all treatments, throughout the whole period, and increasingly with time, wide differences were observable in the different layers, whilst even in the swaths after 54 hours and under the favourable drying conditions obtaining, there was still a considerable difference between the top and bottom layers. At the 54-hours period samples were taken from different layers in each of the treatments and their moisture-contents determined separately; the results, which are given in Table 5, well illustrate the wide variability in the amount of drying which had taken place.

It is certain that preliminary partial drying in the field, under any method, must almost always result in producing material having a considerable variation in moisture-content, a factor which may need to be taken into account in the subsequent artificial drying of the material.

TABLE 5. *Percentage of Moisture in Grass in Different Layers after 54 Hours Field-drying*

Position of Sample	*Swaths*	*Windrows*	*Heaps*
Top layer .	40·7	39·3	39·7
Middle layer .	. .	. .	73·6
Bottom layer .	55·9	72·0	75·4
Average sample* .	49·2	57·7	68·1

* Representative of treatment—see Table 3.

Effect of Preliminary Drying on the Nitrogenous Constituents of the Grass

(*a*) *Total nitrogen.*—The average values for the percentage total nitrogen-content of the dry matter, which are given in Table 6, show that preliminary drying had little, if any, effect in any of the treatments on the total nitrogen or crude-protein content of the grass.

TABLE 6. *Average Values for Percentage Total Nitrogen in Dry Matter*

Method of Drying	*Period of Drying (hours)* 0	6	9	24	30	48	54	*Standard Error*	*Significant Difference*
Swaths . .	2·60	2·53	2·73	2·65	2·69	2·62	2·66	0·050	0·16
Windrows .	2·80	2·83	2·70	2·81	2·76	2·77	2·88	0·047	0·15
Heaps . .	2·65	2·66	..	2·67	2·68	..	2·77	0·028	0·09

(*b*) *Stützer and pepsin-digestible nitrogen.*—The values for the percentages of Stützer and pepsin-digestible nitrogen in the dry matter, given in Table 7, again show little, if any, effect of preliminary drying in any of the treatments. It may be safely assumed, therefore, that preliminary partial drying in the field, besides having practically no effect on the amount of crude protein, was also without significant effect on the nature of the main individual constituents thereof.

TABLE. 7. *Values for Percentage Stützer and Pepsin-digestible Nitrogen in Dry Matter**

Method of Drying	*Period of Drying (hours)* 0	6	24	30	54
	Stützer Nitrogen (per cent.)				
Swaths . .	2·38	2·20	2·29	2·31	2·22
Windrows .	2·41	2·49	2·40	2·39	2·34
Heaps . .	2·32	2·37	2·31	2·30	2·28
	Pepsin-digestible Nitrogen (per cent.)				
Swaths . .	2·22	2·14	2·23	2·28	2·26
Windrows .	2·38	2·34	2·37	2·32	2·44
Heaps . .	2·23	2·22	2·25	2·28	2·35
	Ratio Stützer: Total Nitrogen				
Swaths . .	0·92	0·87	0·86	0·86	0·84
Windrows .	0·86	0·88	0·85	0·87	0·81
Heaps . .	0·88	0·89	0·87	0·86	0·82
	Ratio Pepsin-digestible: Total Nitrogen				
Swaths . .	0·85	0·85	0·84	0·85	0·85
Windrows .	0·85	0·83	0·84	0·84	0·85
Heaps . .	0·84	0·84	0·84	0·85	0·85

* Determinations made on weighted composite samples. No determinations made at 9- and 48-hours periods.

Effect of Preliminary Drying on the Carotene-content of the Grass

Composite samples of the fresh grass for each drying treatment were examined for carotene-content initially, and after intervals of 6, 24, 30,

48, and 54 hours. No general differences in carotene-content among the three treatments were discernible at any one period, partly, perhaps, owing to a certain amount of variability among the values obtained; so only the mean values for the three treatments are given in Table 8. A moderately rapid loss of carotene occurred immediately following cutting, amounting to about 14 per cent. at the 6-hours period, and was followed by a much reduced rate of loss until after 54 hours' drying the carotene-content had been reduced by about 22 per cent. of its original value. From the nutritive point of view, however, these losses were not serious, the actual amount of carotene remaining after 54 hours still being adequate for nutrition.

It is, of course, probable that the losses in carotene from the outer layers were greater, and those from the inner layers lower, than the average values given. It was noticed that the outer layers were bleached in measurable degree, whilst the inner layers had retained better their green colour.

TABLE 8. *Average Carotene-content of all Preliminary Drying Treatments*

(mgm. per cent. of dry matter)

Period of Drying (hours)

0	*6*	*24*	*30*	*48**	*54*
42·0	36·3	35·0	35·2	32·8	32·7

* Average of swaths and windrows only.

Discussion

The main conclusions drawn from the results are as follows. Under good but comparatively cool weather conditions in May, the preliminary partial drying of freshly cut grass in the field may be undertaken successfully with an appreciable reduction in the water-content of the grass, with little if any change in the dry matter and the nitrogenous constituents, and with only a moderately small reduction in the carotene-content. Of the three methods of drying employed, drying in the swaths as cut proved more satisfactory than first collecting the grass into windrows or heaps. All forms of drying, however, resulted in grass having a very variable moisture-content.

How far similar results would obtain under other climatic conditions must be at present a matter of conjecture. The effects of rainfall and of higher temperatures in particular require study, whilst the nature and condition of the grass itself may also influence the results. Dry weather at this Station during the summer of 1935 again prevented a continuation of the investigation on the lines described.

Summary

The results are presented of a replicated experiment in which freshly cut grass, at a stage of growth suitable for conservation, was first partially dried in the field under good but comparatively cool weather conditions in May, in the form of (*a*) swaths as cut, (*b*) windrows (four

swaths raked together), and (*c*) heaps of 100 lb. fresh grass, for 54 hours, samples being taken initially and at intervals of 6, 9, 24, 30, 48, and 54 hours and examined for yield of fresh grass and dry matter, for total, Stützer, and pepsin-digestible nitrogen, and for carotene-content.

In all treatments drying was practically without effect on the yield of dry matter and on the total nitrogen and its above-named constituents. The average carotene-content was reduced by about 14 per cent. after 6 hours', and by about 22 per cent. after 54 hours' drying, in all treatments.

Drying effected a significant decrease in the average values for the percentage of water in the grass up to the 30-hours period for the swaths, 48 hours for the windrows, and 24 hours for the heaps; beyond these periods no, or little, further loss of water occurred. At these periods the original moisture-content of approximately 75 per cent. had been reduced to average values of approximately 54, 58, and 70 per cent. in the swaths, windrows, and heaps respectively. A feature in all treatments was the non-uniformity of drying; as was to be expected, the grass of the outer exposed layers dried more rapidly and to a greater degree than that of the inner less exposed layers.

The economic importance of preliminary partial drying in the field and the consequent significance of the results of this investigation in the conservation of grass by artificial drying are discussed, and the necessity for studying the effects of preliminary partial drying under other climatic conditions is pointed out. The effects of rainfall, of higher temperatures, and of the nature and condition of the grass itself are suggested as the subject of future study.

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EXPERIMENTS ON THE NITROGENOUS MANURING OF SUGAR-BEET

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In 1925 experiments were begun at the Norfolk Agricultural Station on the following problems in the manuring of sugar-beet:

1. The economic limit in the use of (*a*) nitrate of lime, (*b*) nitrate of soda, (*c*) sulphate of ammonia.
2. Comparison of sulphate of ammonia and nitrate of soda as a source of nitrogen.
3. The time of application of sulphate of ammonia.
4. The effect of heavy dressings of muriate of potash.

The majority of the experiments were carried out on the Station's farm at Sprowston, which is typical of much land in central Norfolk, the soil being a light loam overlying brick earth and not in a particularly high state of fertility. The experiments with sulphate of ammonia were also carried out on a number of farms in the county of Norfolk.

With the exception of those carried out in 1925, all the experiments were laid down in Latin squares. The size of the plots varied from 1/40th to 1/100th acre. In the experiments carried out at Sprowston, all the beets from each plot were washed before weighing, but in the county trials the beets were weighed dirty in the field and sampled for dirt-tare. Up to 1930, sugar-content was estimated on bulked samples for each treatment, ten beets being taken from each plot. After 1930, the estimations were made separately for each plot, the sample consisting of 20 roots per plot.

The experiments cover a period of nine years, the rainfall figures for which are given in Table 1.

TABLE 1. *Rainfall at Sprowston, Norfolk, 1925–33*

Year	*April, May, and June inclusive*	*July–November inclusive*	*Total April–November*
	inches	inches	inches
1925	4·58	12·32	16·90
1926	6·18	10·56	16·74
1927	7·24	18·45	25·69
1928	5·57	9·69	15·23
1929	2·94	11·88	14·82
1930	6·15	18·15	24·30
1931	9·45	11·48	20·93
1932	7·41	13·78	21·19
1933	5·11	9·30	14·41
Normal	5·33	12·47	17·80

The rainfall at Sprowston for the eight months April to November was considerably below normal in 1928, 1929, and 1933, but in 1927, 1930,

1931, and 1932 it was appreciably above normal; 1925 and 1926 were the only two years with rainfall approximating to the normal.

The Economic Limit in the Use of Various Nitrogenous Manures

(*a*) *Nitrate of Lime.*—Nitrate of lime is not now very widely used for sugar-beet owing to its relatively low nitrogen-content and to handling difficulties. Experiments with different quantities of this fertilizer were, however, carried out at Sprowston in 1925–6–7. The quantities tested were 1 cwt., 3 cwt., and 4 cwt. per acre, and a basal dressing of 12 loads per acre farm-yard manure, 3 cwt. per acre superphosphate, and 1 cwt. per acre muriate of potash, was applied to all the plots. The results for each year are given in Appendix I and the means of the three years in Table 2.

TABLE 2. *Response of Sugar-beet to Increasing Applications of Nitrate of Lime*

	Nitrate of Lime, cwt. per acre			
	0	*1*	*3*	*4*
Washed beet, tons per acre	10·6	11·2	11·5	12·1
Per cent. of mean	93	98	101	107
Sugar-content per cent.	17·4	17·3	17·0	17·1
Sugar, cwt. per acre	36·8	39·0	39·5	41·5
Per cent. of mean	94	100	101	105
Tops, tons per acre	6·0	6·3	7·3	8·2
Per cent. of mean	87	91	105	119

The first cwt. of fertilizer gave an increase in yield of 0·6 tons, though the weight of tops was only raised slightly. The second and third cwt., on the other hand, gave only a small increase in yield of beet, but the weight of tops was raised by 1 ton per acre. It is evident that the fourth cwt. gave an economic response over the third cwt., for the weight of beet and of tops was raised by 0·6 tons and 0·9 tons, respectively.

These experiments were, however, carried out on soils not deficient in lime, and it may be that nitrate of lime would prove to be more valuable still on soils that are acid or are on the border-line of acidity.

(*b*) *Nitrate of Soda.*—The trials dealing with the use of varying quantities of nitrate of soda were begun at Sprowston in 1925 and continued in the following two years. Four quantities were tested, 1 cwt., 2 cwt., 3 cwt., and 4 cwt. per acre, the first cwt. being applied at seeding, the second at brairding, and the third and fourth immediately after singling. Thus the applications of 3 cwt. and 4 cwt. per acre were made in three separate dressings. In each year the basal manuring per acre was: 12 loads farm-yard manure, 3 cwt. 30 per cent. superphosphate, and 1 cwt. muriate of potash per acre. The yield figures for each of the three years are given in Appendix II, and the means of the three years are set out in Table 3. The rainfall in the first two years was close to the normal for the district, but from April to November in 1927 it was 45 per cent. above normal.

TABLE 3. *Response of Sugar-beet to Increasing Applications of Nitrate of Soda*

	Nitrate of Soda, cwt. per acre				
	0	*1*	*2*	*3*	*4*
Washed beet, tons per acre	10·3	11·7	12·1	12·6	12·4
Per cent. of mean	87	99	102	107	105
Sugar-content, per cent.	17·6	17·5	17·3	17·3	17·1
Sugar, cwt. per acre	36·4	41·2	42·0	43·6	42·7
Per cent. of mean	88	100	102	106	104
Tops, tons per acre	5·5	6·4	7·6	8·0	9·0
Per cent. of mean	75	88	104	110	123

The systematic lay-out of the 1925 experiment did not allow a standard error to be calculated, but the yields show the same trend as those in 1926 and 1927. In these last two years, however, there was no significant increase in yield beyond that obtained with 2 cwt. per acre of nitrate of soda, though in all three years there were indications that 3 cwt. per acre gave an economic response.

Further experiments at Sprowston have measured the response of the beet crop to 3 cwt. per acre of nitrate of soda, and the results are available for the nine years 1925–33 (Table 4). In every year after 1927, all the nitrate of soda was applied to the seed-bed, experiments [1] having shown seed-bed application to give quite as good results as top-dressing. The basal manuring per acre was the same each year, viz. 12 loads f.y.m., 3 cwt. 30 per cent. superphosphate, and 1 cwt. muriate of potash per acre.

TABLE 4. *Response of Sugar-beet to 3 cwt. per acre of Nitrate of Soda, nine years, 1925–33*

Year	*Increased weight of washed beet per acre*		*Standard error*	*Decrease in sugar-content*	*Increased weight of sugar per acre*	
	tons	*% increase*	*tons*		*cwt.*	*% increase*
1925	2·9	32	..	0·7	8·4	26
1926	2·4	20	0·35	0·3	7·8	18
1927	1·5	15	0·28	Nil	5·2	15
1928	0·8	7	0·28	0·5	3·8	9
1929	1·7	15	0·20	0·2	5·9	13
1930	2·7	25	0·22	Nil	8·9	25
1931	1·9	17	0·32	Nil	6·4	16
1932	0·8	6	0·24	Nil	2·6	6
1933	1·0	8	0·19	0·4	2·4	5
Mean	1·8	16	..	0·3	5·8	15

In each year (except 1925, when no error could be calculated) there has been a significant increase in yield due to the application of 3 cwt. of nitrate of soda, though there is considerable variation from year to year. The biggest increase in yield of washed beet was 2·9 tons per acre (or 32 per cent.) in 1925; the smallest 0·8 tons per acre (6 per cent.) in 1932. It is difficult to state definitely what is the reason for this variation. Season, the different fertility-levels of the fields on which the experi-

ments were carried out, and the small variations in the date of drilling and lifting, would all tend to affect the results, and it is impossible to assess the influence of one factor independently of the others. Experiments in two of the years did show, however, that time of lifting did not materially affect the response to nitrate of soda, although, of course, the yields generally were lower with early lifting.

The drop in sugar-content also shows considerable variation, ranging from nil in four of the years, to 0·7 per cent. in 1925. The four years when the sugar-content was not depressed were 'wet' years, and in the three dry years (1928, 1929, and 1933) there was a drop in sugar-content of 0·5, 0·2, and 0·4 per cent., respectively. It appears, therefore, that the depression of sugar-content by nitrogenous manuring varies according to season, for there is a difference in the rate of maturity of the crop in the two types of season. In a dry season, the plants receiving no nitrogenous fertilizer would tend to mature more rapidly; in a wet season, maturity is delayed, as growth continues late and the unmanured plants tend to make growth as late as the manured plants. In a dry season it was usually easier to pick out the control plots than in a wet season, by the greater yellowing of the leaves in the autumn.

(*c*) *Sulphate of ammonia.*—The experiments with sulphate of ammonia were carried out in 1928 on six farms in Norfolk. The amounts of fertilizer applied were 1 cwt., 2 cwt., and 3 cwt. per acre; in each case all was applied on the seed-bed. A basal manuring of phosphate, potash, and f.y.m. was applied at each centre.

The results at the individual centres are given in Appendix III, and the means for the light-loam centres and the heavy-loam centres in Table 5.

TABLE 5. *Response of Sugar-beet to Increasing Applications of Sulphate of Ammonia*

	Sulphate of Ammonia, cwt. per acre			
	0	*1*	*2*	*3*
Washed beet, tons per acre:				
3 light loams	8·6	9·2	9·6	9·7
3 heavy loams	12·0	12·7	13·6	14·2
Sugar-content:				
3 light loams	19·5	19·1	19·1	19·2
3 heavy loams	20·2	20·3	20·1	20·0
Sugar, cwt. per acre:				
3 light loams	33·8	35·3	36·9	37·7
3 heavy loams	48·8	51·7	55·0	56·9

At each centre there was a gradual increase in the yield of roots with each cwt. of sulphate of ammonia up to 2 cwt. Three cwt. per acre gave no further increase in yield except at Sutton and Uphall, both heavy loam centres and well farmed. At Westacre (a light-land centre), on the other hand, there was a slight but not significant response to 1 cwt. per acre of sulphate of ammonia, and no increase in yield was obtained with additional amounts of nitrogen. From the above figures, 2 cwt. per acre of sulphate of ammonia appears to be the economic maximum, except perhaps on the more fertile soils. The year 1928, however, was a dry

year, which may have prevented the fertilizer from exerting its fullest influence. Of two subsequent trials at Sprowston, only one has shown a significant response to the third cwt.

The increase in yield due to the use of 2·2 cwt. per acre of sulphate of ammonia has been measured at Sprowston during six successive years (Table 6). All the sulphate of ammonia was applied in one dressing on the seed-bed, the same basal dressing of f.y.m., superphosphate, and muriate of potash being applied each year.

TABLE 6. *Response of Sugar-beet to 2·2 cwt. per acre of Sulphate of Ammonia, six years, 1928–33*

Year	*Increased weight of washed beet per acre*		*Standard error*	*Decrease in sugar-content*	*Increased weight of sugar per acre*	
	tons	*% increase*	*tons*		*cwt.*	*% increase*
1928	0·1	1	0·23	0·4	−0·5	−1
1929	1·5	13	0·20	0·1	6·0	14
1930	1·1	10	0·22	0·1	3·3	9
1931	1·0	9	0·33	0·1	3·7	10
1932	0·1	1	0·38	0·3	1·3	3
1933	0·3	2	0·20	0·6	−0·5	−1
Mean	0·7	6	..	0·3	2·2	6

In three of the years (1929–30–31) a significant increase in yield due to sulphate of ammonia was obtained. In the remaining three years, slight responses were secured, but they were not significant. Reference to the rainfall table on page 152 does not show any marked relationship between the amount of rainfall and the response of the crop to sulphate of ammonia in these years. Of the three years in which no response to the fertilizer was obtained (1928, 1932, and 1933), the rainfall from April to November in 1928 and 1933 was below normal. Examination of the individual monthly rainfall figures also does not give consistent results. The seed was drilled and the crop lifted at approximately the same time each year, which should rule out any effects of difference in time of maturity. It is more than likely that the difference in the state of fertility of the various fields on which the experiments were laid down have influenced the magnitude of the response to sulphate of ammonia.

Also, it is possible that the potash-content of the soil influences to some extent the action of the sulphate of ammonia. If this is so, then it is not unlikely that the variation in the response to sulphate of ammonia might be due to the different potash levels of the fields on which the experiments were made. This is suggested by the fact that little response to sulphate of ammonia was obtained in 1928 at Sprowston, whereas a response was obtained on other farms (particularly the heavy-land farms) in Norfolk in that year.

Comparison of Nitrate of Soda and Sulphate of Ammonia

To provide some information on the relative efficiency of nitrate of soda and sulphate of ammonia when compared on an equivalent-nitrogen

basis, experiments were carried out at Sprowston in the six years 1928–33. The rates of application were 3 cwt. per acre of nitrate of soda, and 2¼ cwt. per acre of sulphate of ammonia, these amounts giving theoretically equal quantities of nitrogen. As in the other experiments, the plots received a basal dressing of f.y.m., potash, and phosphate, all the artificials being applied before drilling. The variety in each year was Kleinwanzleben E.

The results for the six years are given in Appendix IV, these years including three years when the rainfall for the district was below normal, and three years when the rainfall was above normal. In each year the nitrate-of-soda plots have given the heavier yield, though in 1929 and 1932 the differences were not significant, and in 1931 the difference of 0·9 tons only just reached significance.

TABLE 7. *Comparison of Nitrate of Soda and Sulphate of Ammonia*

(Equivalent-nitrogen Basis)

	No Nitrogen	*2¼ cwt. per acre Sulph. of ammon.*	*3 cwt. per acre Nitr. of soda*	*Difference in favour of Nitr. of soda*
Washed beet, tons per acre	11·9	12·7	13·4	0·7
Per cent. of mean	94	100	106	6
Sugar-content	17·5	17·4	17·4	Nil
Sugar per acre, cwt.	41·7	44·3	46·6	2·3
Per cent. of mean	94	100	106	6

Over the average of the six years (Table 7), 3 cwt. per acre of nitrate of soda has given 0·7 tons (6 per cent.) per acre of washed beet more than 2¼ cwt. of sulphate of ammonia. Owing to the difficulty of separating seasonal effects from other factors likely to influence the yield, it is not possible to draw any conclusions as to the relative efficiency of these two fertilizers in a wet year and in a dry year.

On equivalent cost-per-acre basis (at 1934–5 prices), nitrate of soda and sulphate of ammonia could be applied in equal quantities, i.e. 3 cwt. per acre of sulphate of ammonia would cost no more than 3 cwt. per acre of nitrate of soda. The yields from these quantities were compared in the 1932 and 1933 experiments (Table 8).

TABLE 8. *Comparison of Nitrate of Soda and Sulphate of Ammonia*

(Equivalent-cost Basis)

		No Nitrogen	*3 cwt. Sulph. amm.*	*3 cwt. Nitr. soda*	*4 cwt. Nitr. soda*	*Standard error*
Washed beet, tons per acre	1932	13·8	14·0	14·7	15·4	0·24
	1933	12·9	14·1	13·9	14·0	0·19
Sugar-content	1932	16·4	16·3	16·5	16·3	..
,, ,,	1933	17·3	16·5	16·9	16·4	0·16
Sugar, cwt. per acre	1932	45·3	45·6	48·5	50·2	..
	1933	44·6	46·6	47·0	45·9	..

The yields from 3 cwt. and 4 cwt. nitrate of soda were significantly heavier than from 3 cwt. of sulphate of ammonia in 1932, but not in 1933. There was little difference in sugar-content in the former year, but in 1933 nitrogen, as sulphate or nitrate, lowered the percentage of sugar. These figures, however, apply only to two years, and though it would be unsafe to argue too widely from them, nevertheless, it would appear advisable, when substituting sulphate of ammonia for nitrate of soda, to effect such substitution on a cwt.-for-cwt. basis and not on an equivalent-nitrogen basis.

Time of Application of Sulphate of Ammonia

In the early years of the beet crop it was the practice to apply the nitrogenous fertilizer in two or three separate dressings, e.g. one-half at seeding and one-half as a top-dressing after singling. Experiments begun in 1927 with nitrate of soda and with a mixture of nitrate of soda and sulphate of ammonia indicated, however, that just as good results could be obtained by applying all the nitrogen to the seed-bed before drilling. If this were possible, then the labour and inconvenience of top-dressing could be avoided. Accordingly, in 1928 experiments were laid down on six farms in Norfolk, in which 3 cwt. per acre of sulphate of ammonia was applied, (*a*) all on the seed-bed, (*b*) half on the seed-bed and half at singling, (*c*) half at singling and half three weeks later. In Table 9 the yields have been averaged for the light-loam centres and the heavy-loam centres. The yields at the individual centres are given in Appendix V. The basal manuring at each centre was typical of the sugar-beet manuring at that farm, consisting of 10–12 loads f.y.m., 2–2½ cwt. superphosphate, and 1–1½ cwt. muriate of potash. There were no differences in plant-population according to the time at which sulphate of ammonia was applied, and a good plant was obtained at all centres.

TABLE 9. *Effects of Applying Sulphate of Ammonia at Different Times*

	3 cwt. per acre of Sulphate of Ammonia		
	All on seed-bed	*½ on seed-bed, ½ at singling*	*½ at singling, ½ 3 weeks later*
Washed beet; tons per acre:			
3 heavy loams	13·7	13·7	13·2
2 light loams	9·3	8·9	8·4
Sugar-content:			
3 heavy loams	20·2	20·2	19·5
2 light loams	18·8	18·8	19·0
Sugar, cwt. per acre:			
3 heavy loams	55·4	55·2	52·9
2 light loams	35·0	33·7	32·4

At three out of the six centres there was no significant difference in yield between the times of application of nitrogen, but at two of the centres (Sutton and Testerton) the very late application of sulphate of ammonia resulted in a significantly decreased yield; possibly these beets

were not fully ripened when lifted, as the sugar-contents seem to indicate. At Westacre the later applications of nitrogen gave the higher yield, but at this centre the field was weedy and the seed-bed applications of nitrogen resulted in an early growth of weeds, which was not apparent with the later applications. Presumably this early growth of weeds indicated that some of the nitrogen had been taken up by them, and was therefore lost to the beet-plants. This occurred only at the one centre, however, and it would seem that its occurrence depends upon whether the land is clean at the start. If the land is weedy, then there is the risk that seed-bed applications may produce a greater early growth of weeds.

On the average, seed-bed application of sulphate of ammonia increased the yield by 3 per cent. in the light loams and by 9 per cent. on the heavier loams, when compared with the very late application. It would seem, therefore, that late applications are more deleterious on the lighter lands than on the heavier lands. It is possible that the moisture-content of the soils at the time the nitrogen is applied may affect the efficiency of the fertilizer. The year 1928 was rather dry in Norfolk, especially from June onwards, and the lighter lands might reasonably be expected to dry out more than the heavier lands, thereby affecting the efficiency of the late applications of nitrogen.

It is sometimes held that late applications of nitrogen lead to a reduced sugar-content in the beet, i.e. ripening is delayed, and at four of the centres this was so, but at one centre (Worstead) the sugar-content was unaffected.

The criticism may be made that these experiments were carried on for one year only and that one year's results cannot be very reliable, especially when the particular year, 1928, was a rather abnormal one for rainfall in Norfolk; but similar experiments with nitrate of soda [1] extending over five years showed that the efficiency of seed-bed application of nitrate of soda was in no way affected by season. Seed-bed application gave just as good results in a wet year as in a dry year, and there seems no reason why similar results should not be obtained with sulphate of ammonia—a fertilizer presumably less readily leached from the soil than nitrate of soda.

The Effect of Heavy Dressings of Muriate of Potash

It has already been mentioned that nitrogenous manuring led to a slight reduction in the sugar-content of the beet. This depression might have been due to unbalanced manuring causing late maturity, and if this were so, it is not unlikely that the application of extra potash might lead to an improvement in sugar-content.

In 1929, therefore, a trial was begun to test the effects of additional potash in the presence of 3 cwt. per acre of nitrate of soda (Table 10). The trial was continued for five years and in each year a basal dressing, per acre, of 12 loads f.y.m., 3 cwt. nitrate of soda, and 3 cwt. 30 per cent. superphosphate was applied. Two rates of potash manuring were tested, 1 cwt. per acre and 3 cwt. per acre of muriate of potash. The latter dressing is perhaps unduly high, but it was considered necessary to provide an ample supply of potash.

TABLE 10. *Effect of Additional Potash with 3 cwt. Nitrate of Soda*

	Washed beet, tons per acre		*Sugar-content*	
	Muriate of Potash, cwt. per acre			
Year	*1*	*3*	*1*	*3*
1929	13·2	13·3	18·7	19·0
1930	13·7	13·6	16·4	16·3
1931	13·3	13·4	17·0	17·1
1932	14·5	14·8	16·5	16·4
1933	13·8	13·9	16·8	17·0
Mean	13·7	13·8	17·1	17·2

In every year the effects of the additional 2 cwt. per acre of muriate of potash were negligible and in no case significant. It is possible that the action of the sodium ions from the nitrate of soda, liberating available potash from the reserves in the soil, may have provided an adequate supply of potash and the addition of extra potash had no effect and was therefore uneconomic.

In 1932 and 1933 new experiments were put down to test if extra potash would be of benefit, (*a*) if 4 cwt. per acre of nitrate of soda was applied instead of 3 cwt., and (*b*) if sulphate of ammonia was used as the source of nitrogen instead of nitrate of soda (Table 11). The former fertilizer is not presumed to have so great an effect on the reserves of potash in the soil, and therefore additional potash manuring when sulphate of ammonia is used might be more advantageous.

TABLE 11. *Effect of Additional Potash with Nitrogenous Fertilizers*

	Washed beet, tons per acre				*Sugar-content*			
Year	*1932*		*1933*		*1932*		*1933*	
Amount of M/P (cwt.)	*1*	*3*	*1*	*3*	*1*	*3*	*1*	*3*
4 cwt. nitr. soda . .	15·4	15·5	13·6	14·4	16·3	16·4	16·6	16·2
2·2 cwt. sulph. ammon.	14·1	15·1	13·1	13·4	16·6	16·4	16·6	16·8
3 cwt. sulph. ammon. .	13·7	15·2	13·9	14·3	16·6	16·1	16·7	16·3
Standard error . .	0·38		0·20		..		..	

Only two significant increases in yield due to potash were obtained in the two years, namely, an increase of 0·8 tons per acre when 4 cwt. of nitrate of soda were used in 1933, and an increase of 1·0 tons per acre when 2·2 cwt. of sulphate of ammonia were used in 1932. At the same time, however, reasonably large increases in yield due to the extra potash were obtained with 3 cwt. of sulphate of ammonia in both years. The effect of the extra potash was not reflected in the sugar percentages, for none of the differences shown in the table were significant.

In view of the difference in the response to additional potash in the two years, it would be unwise to attach too much importance to the results. At the same time, however, it is difficult entirely to disregard

the evidence. The Rothamsted experiments [2] have shown that potash is likely to be beneficial when sulphate of ammonia is used, but with nitrate of soda the benefits were not so marked. Taken together, the evidence suggests that if high dressings of nitrogen are applied then additional potash will probably be advantageous, the more so if sulphate of ammonia be used, and the soil is known to respond to potash.

Summary

1. Experiments carried out in Norfolk on the nitrogenous manuring of sugar-beet are described.

2. In three-years experiments at Sprowston, the optimum amount of nitrate of lime was 4 cwt. per acre, and of nitrate of soda 3 cwt. per acre.

3. A significant response to 3 cwt. per acre of nitrate of soda was obtained each year during the nine years 1925–33.

4. In 1928 the optimum amount of sulphate of ammonia was 2 cwt. per acre at four centres. The third cwt. gave an increase in yield only on the more fertile soils.

5. Only in three of the six years 1928–33 was a significant response to 2·2 cwt. of sulphate of ammonia obtained at Sprowston.

6. In four trials at Sprowston 3 cwt. per acre of nitrate of soda gave a significantly heavier yield than 2·2 cwt. of sulphate of ammonia.

7. In experiments on six farms in 1928, 3 cwt. per acre of sulphate of ammonia applied all on the seed-bed gave at least as good results as splitting the dressing into two or three parts. Late applications of nitrogen depressed the yield at two centres and the sugar-content at four centres.

8. Additional potash did not raise the yield or sugar-content when 3 cwt. per acre of nitrate of soda was used. With 4 cwt. per acre of this fertilizer, and with sulphate of ammonia, evidence was obtained that increasing the potash manuring might raise the yield.

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1. E. T. Sykes, J. Min. Agric., 1931, **38**, 162–70; 1932, **39**, 104–5.
2. Rothamsted Experimental Station, Report for 1930, p. 34.

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APPENDIX I

Increasing Quantities of Nitrate of Lime

Amount of N. of Lime (cwt. per acre)	*Washed beet (tons per acre)*			*Tops (tons per acre)*		
	1925	*1926*	*1927*	*1925*	*1926*	*1927*
0	9·3	12·3	10·1	5·8	5·5	6·6
1	9·8	13·1	10·8	6·2	6·2	6·5
2	9·6	13·9	11·1	7·6	7·2	7·1
4	10·3	14·2	11·7	8·7	8·3	7·5
Standard error	..	0·22	0·17	..	0·32	0·31

Amount of N. of Lime (cwt. per acre)	*Sugar (cwt. per acre)*			*Sugar-content (per cent.)*		
	1925	*1926*	*1927*	*1925*	*1926*	*1927*
0	31·8	44·0	34·5	17·1	17·9	17·1
1	33·2	47·0	36·9	16·9	17·9	17·1
2	30·7	50·0	37·8	16·0	18·0	17·0
4	32·8	50·9	40·7	15·9	17·9	17·4

APPENDIX II

Increasing Quantities of Nitrate of Soda

Amount of N. of Soda (cwt. per acre)	*Washed beet (tons per acre)*			*Tops (tons per acre)*		
	1925	*1926*	*1927*	*1925*	*1926*	*1927*
0	9·3	11·7	11·0	5·0	5·3	6·1
1	11·2	13·0	11·0	6·0	5·8	7·3
2	10·8	13·8	11·7	6·8	8·2	7·7
3	12·1	14·2	11·5	7·2	9·0	7·8
4	11·1	14·6	11·5	9·0	9·3	8·6
Standard error	..	0·35	0·28	..	0·51	0·59

Amount of N. of Soda (cwt. per acre)	*Sugar (cwt. per acre)*			*Sugar-content (per cent.)*		
	1925	*1926*	*1927*	*1925*	*1926*	*1927*
0	32·6	42·1	34·6	17·5	18·0	17·3
1	38·5	46·9	38·1	17·2	18·0	17·3
2	36·5	48·9	40·5	16·9	17·7	17·3
3	40·6	50·3	39·8	16·8	17·7	17·3
4	36·2	52·0	39·8	16·3	17·8	17·3

APPENDIX III

Increasing Quantities of Sulphate of Ammonia

Washed Beet (tons per acre)

Centre: *Soil (loam):*	*Worstead* heavy	*Sutton* heavy	*Uphall* heavy	*Bridgham* light	*Westacre* light	*Testerton* light	*Mean*	*Per cent.*
Amt. of Sulph. Ammon. (cwt. per acre)								
0	11·8	11·2	13·1	11·3	7·4	7·0	10·3	92
1	12·2	11·5	14·5	11·8	8·0	7·7	10·9	97
2	13·3	12·4	15·2	12·4	8·2	8·1	11·6	104
3	13·3	13·3	16·1	12·7	8·2	8·2	12·0	107
Standard error	0·43	0·31	0·34	0·18	0·33	0·34	..	..

Sugar-content

Centre:	*Worstead*	*Sutton*	*Uphall*	*Bridgham*	*Westacre*	*Testerton*	*Mean*
Amt. of Sulph. Ammon. (cwt. per acre)							
0	20·6	19·5	20·6	20·7	19·6	18·2	19·9
1	20·2	19·8	20·8	20·1	19·1	18·0	19·7
2	20·1	19·5	20·7	20·1	19 0	18·2	19·6
3	19·9	19·7	20·3	20·6	19·1	18·0	19·6

Sugar (cwt. per acre)

Centre:	*Worstead*	*Sutton*	*Uphall*	*Bridgham*	*Westacre*	*Testerton*	*Mean*	*Per cent.*
Amt. of Sulph. Ammon. (cwt. per acre)								
0	48·6	43·7	54·0	46·8	29·0	25·5	41·3	93
1	49·3	45·5	60·4	47·5	30·6	27·7	43·4	97
2	53·5	48·4	63·0	50·0	31·2	29·5	45·9	103
3	53·0	52·4	65·4	52·4	31·3	29·5	47·3	107

APPENDIX IV

Comparison of Nitrate of Soda and Sulphate of Ammonia

Washed beet (tons per acre)

Year	*1928*	*1929*	*1930*	*1931*	*1932*	*1933*
No nitrogen . . .	11·1	11·4	11·0	11·4	13·8	12·9
2½ cwt. S/A . . .	11·2	12·9	12·1	12·4	14·6	13·3
3 cwt. N/S . . .	11·9	13·2	13·7	13·3	14·7	13·9
Standard error	0·23	0·20	0·22	0·33	0·24	0·19

Sugar-content

Year	*1928*	*1929*	*1930*	*1931*	*1932*	*1933*
No nitrogen . . .	19·2	18·9	16·4	17·0	16·4	17·3
2½ cwt. S/A . . .	18·8	19·0	16·3	17·1	16·5	16·7
3 cwt. N/S . . .	18·7	18·7	16·4	17·0	16·5	16·9

Sugar (cwt. per acre)

Year	*1928*	*1929*	*1930*	*1931*	*1932*	*1933*
No nitrogen . . .	42·6	43·1	36·0	38·8	45·2	44·6
2½ cwt. S/A . . .	42·1	49·0	39·4	42·5	48·2	44·5
3 cwt. N/S . . .	44·5	49·4	45·0	45·2	48·5	47·0

APPENDIX V

Time of Application of Sulphate of Ammonia

Washed beet (tons per acre)

Centre: *Soil (loam):*	*Worstead* heavy	*Sutton* heavy	*Uphall* heavy	*Bridgham* light	*Westacre* light	*Testerton* light	*Mean**	*Per cent.**
3 cwt. S/A: All on seed-bed	12·0	13·5	15·5	11·0	7·6	7·5	11·9	102
½ on seed-bed, ½ at singling	11·8	13·5	15·7	10·7	8·5	7·1	11·8	101
½ at singling, ½ 3 weeks later	11·8	12·8	15·0	10·3	8·6	6·5	11·3	97
Standard error	0·17	0·21	0·40	0·57	0·31	0·18	..	..

* Excluding Westacre.

Sugar-content (per cent.)

Centre:	*Worstead*	*Sutton*	*Uphall*	*Bridgham*	*Westacre*	*Testerton*	*Mean**
3 cwt. S/A: All on seed-bed	20·0	19·7	20·9	19·4	19·5	18·1	19·6
½ on seed-bed, ½ at singling	20·1	19·5	20·9	19·6	18·5	17·9	19·6
½ at singling, ½ 3 weeks later	20·1	19·1	20·2	20·1	17·8	17·9	19·5

* Excluding Westacre.

Sugar (cwt. per acre)

Centre:	*Worstead*	*Sutton*	*Uphall*	*Bridgham*	*Westacre*	*Testerton*	*Mean**	*Per cent.**
All on seed-bed	48·0	53·2	64·9	42·7	29·6	27·2	47·2	102
½ on seed-bed, ½ at singling	47·5	52·6	65·6	42·0	31·4	25·4	46·6	101
½ at singling, ½ 3 weeks later	47·5	48·9	60·6	41·5	30·6	23·3	44·4	97

Excluding Westacre.

THE INCIDENCE OF KEMP IN THE FLEECE OF SCOTTISH MOUNTAIN BLACKFACE SHEEP, WITH SPECIAL REFERENCE TO INHERITANCE

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WITH PLATES 11, 12

Introduction.—The investigations described in this paper were undertaken to determine whether hereditary factors control the presence of kemp fibres in the fleeces of Scottish Mountain Blackface sheep and, if evidence of heredity were found, to attempt to elucidate the mode of inheritance concerned.

The belief that kemp fibres depend for their expression upon hereditary factors is widely held by sheep-breeders, and in particular perhaps by owners of Scottish Mountain Blackface flocks. Barker [1] and Darling [2], dealing with Scottish Blackface sheep, and Roberts [3], dealing with the Welsh Mountain breed, *inter alia*, have put forward generalized evidence that kemp fibres are inherited in differing degrees in individual sheep. Scientific data relating to the inheritance of kemp accumulated from fleece-analyses of flocks of pedigree sheep have not, however, so far been published for the Scottish Mountain Blackface breed, with the exception of one paper by the writer [4].

Definition of kemp fibres.—In the Blackface breed the kemp fibres which are found in most fleeces do not differ markedly from those found in other breeds. They are easily recognized by their macroscopic characters, as follows:

1. The fibres have a dead-white appearance due to a large medulla, containing air, which causes light to be refracted. If pigment is present they are brown or black.
2. Typical kemp fibres show a pronounced wave in one plane only.
3. In most cases they are very coarse.
4. Their length-range varies between 1 and 3 in. when mature. The great majority of Blackface kemp fibres are included in this range; occasionally there are exceptions, but these are not sufficiently numerous to merit special notice.
5. All typical kemps exhibit a sudden thinning to a very fine tip at their distal extremities. At the proximal extremity of a completely grown fibre there is also a slight thinning immediately above the level of the follicle. This can be observed only in fibres which have been shed naturally, and the thin proximal portion of the shaft is followed by a terminal bulb. This thinned portion can seldom be seen in kemp clipped from living sheep.
6. Kemp fibres are extremely brittle.

Material and Methods

(*a*) ***Distribution of kemp over the body.***—In this investigation (which was begun in the autumn of 1930 and carried out at the Institute of

Animal Genetics, University of Edinburgh) it was necessary to find some reasonably accurate method of comparing the amount of kemp present in fleeces of living sheep. Darling [2] showed that the distribution of kemp over the body varied considerably, and it was clear from this work and from general observation that in most sheep little or no kemp was present in the shoulder regions and on the thorax, even in animals which exhibited much kemp in dorsal areas.

Some important observations on the distribution of kemp in the Blackface fleece were made by Prof. Wm. C. Miller, to whom the writer is greatly indebted for permission to use the data and photographs shown in Figs. 2–5, Plates 11, 12, and described below.

One of the Blackface ewes kept at the Institute of Animal Genetics died from peritonitis and there was some delay in disposing of the carcass. Rapid decomposition set in, and about three days after death the wool fibres and long-hair fibres could be easily pulled out, but the kemp fibres were still held firmly in their follicles. All wool and long-hair fibres were removed by hand, and photographs of the carcass, with the kemp fibres *in situ*, were obtained. Subsequently, pieces of skin, each of 1 sq. in., were removed from various locations and the kemp fibres on each were counted. This procedure was repeated with other Blackface sheep which died, and with some which were slaughtered for other experimental reasons. Every carcass was not found to be satisfactory, and only those in which wool and long-hair fibres could be readily plucked without disturbing kemp fibres were used.

In each case very similar results were obtained. The kemp fibres were found to be distributed very densely over a bilaterally symmetrical area on the dorsal aspect of the sheep, extending from about the level of the eighth thoracic vertebra to the tail-head, and for about 2 in. laterally on each side of the mid-dorsal line, becoming broader posteriorly over the croup. Outside this area the density was found to decrease somewhat and, at 4–5 in. from the mid-dorsal line, the occurrence of kemp practically ceased except over the rump, where the dorsal area spread out and extended downwards over the flanks; the density, however, was considerably less in the latter region. The thorax was found to be almost free from kemp, except for one or two small tufts, but the lower parts of the abdomen showed a fair incidence of kemp fibres, though their density in this area was not high. The above description is illustrated by Figs. 2–5, Plates 11, 12. These photographs all relate to the same carcass and are included as being typical of the results obtained in this analysis of the distribution of kemp over the body.

A diagrammatic representation of the locations of the areas from which square inches of skin were removed is given in Fig. 1, and details of the actual numbers of kemp fibres counted in a typical case will be found in Table 1.

It will be seen that the variability of the density of distribution of kemp was low between areas I, II, and III, but became higher in areas IV and V. The variability between areas VI to X was clearly very high, and the density in each of these areas was lower than that of areas I to III. In other words, the variability of the density of kemp-distribution

was very low in a bilaterally symmetrical area extending from a point somewhat in front of the last rib to the level of the croup and for about $1\frac{1}{2}$ in. on each side of the mid-dorsal line. Further, the density-distribution in this area was maximal for the whole skin-surface.

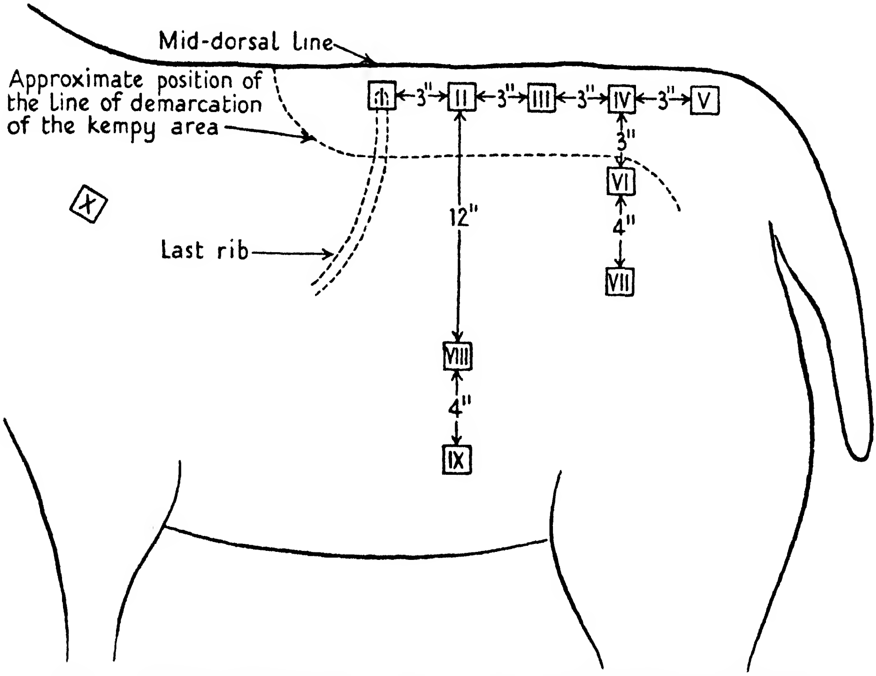

FIG. 1. Diagram showing the locations of the areas of skin removed from carcass of Blackface ewe

These observations, replicated a number of times, were found to agree closely with the results of a detailed analysis of the distribution of kemp over the body in the Welsh Mountain breed made by Roberts [5].

TABLE 1. *Number of Kemp Fibres per sq. in. of Skin in Various Locations on Carcass of Blackface Ewe**

No. of skin sample	*No. of kemp fibres*
I (over head of last rib)	706
II	646
III	696
IV	593
V	425
VI	296
VII	578
VIII	122
IX	401
X (centre of spine of scapula)	254

* Figures for the left side only are given.

(*b*) *Methods of sampling.*—Two samples of wool were removed from each sheep used in these investigations. Uniformity in sampling was assured by selecting definite anatomical points, viz. the head of the last rib on each side. These points are readily found by touch on the living sheep, and the areas used for sampling were, in every case, just medial to them. The approximate size of each sampled area of skin was 2½ sq. cm., and the medial edge of each area was about 1 in. from the mid-dorsal line. Consequently, all samples were removed from situations well within the area of maximum kemp referred to in the preceding section.

As the maximum-growth period of kemp fibres terminates about the end of October, it was decided that the most suitable time for sampling would be during November, when kemp fibres had ceased to grow and before shedding became general; this practice has been followed throughout this investigation.

It has been shown by Lochner [6] that birthcoat-fibres may persist in the Blackface fleece for up to a year after birth. Also, the accuracy of any comparison of fleeces from sheep under a year old with those from adult sheep tends to be vitiated by the fact that the fleece of the young sheep represents the growth of fibres from some time before birth, whilst the adult fleece represents fibre-growth from the time of the last shearing only. It was decided, therefore, that the youngest sheep which could be used for sampling would be approximately 18 months old; that is, their fleeces were sampled in the November following their first shearing.

(*c*) *Material used.*—The sheep that provided most of the material for this work consisted of a private pedigree Blackface flock which had been most accurately recorded for the previous ten years. As the flock-book was placed at the writer's disposal, the ancestry of each sheep sampled was available for consideration.

In addition, wool samples were obtained from stud rams belonging to breeders in different parts of Scotland.

(*d*) *Laboratory treatment of the samples.*—Each sample was divided by hand into a non-kemp fraction and a kemp fraction, and the fractions were de-greased and scoured by the process described by Miller and Bryant [7]. Since it was shown by Barritt and King [8] that the rates of moisture re-gain for all classes of fleece-fibres are almost identical, the fractions, after scouring, were allowed to 'condition' to laboratory humidity, were then weighed, and the percentage weights of kemp were calculated. The means of the percentage weights of kemp in the two samples removed from each sheep were found, thus providing a single kemp-analysis figure for each animal.

Results

The data accumulated from the analyses of the wool samples collected as described above are set out and explained below.

Although samples were obtained from some 500 sheep in the experimental flock, owing to the impossibility of obtaining comparable wool samples from sheep less than 18 months old, comparisons between the percentages of kemp from dams and their offspring had to be limited to

sheep which were adult (18 months old at least) when samples were collected. This accounts for the small number of dam-to-progeny comparisons.

Since the sires of a number of the experimental ewes sampled had been disposed of before this work was begun, it was not possible to compare the kemp-contents of some of the ewes' fleeces with those of their sires. Further, in each year of the flock-book records, the sires of about 10 per cent. of the lambs born were not definitely known, owing to accidental mistakes in reading numbers, tags being torn out of sheep's ears, and other causes. Later analyses were made only of samples from sheep of which at least one of the parents had been sampled.

The ages of the experimental sheep ranged from 1½ to 4½ years. The fleeces of sheep older than this were not analysed. The question of the influence of age on kempiness will be discussed later.

The relationship between the analysis-figures for the kemp of 11 rams and 143 of their female progeny is shown in Table 2, and of 72 ewes and their progeny (one daughter per ewe) in Table 3. To obtain

TABLE 2. *Relationship between Percentage of Kemp in Rams and Percentage of Kemp in their Offspring*

CORRELATION TABLE

RAMS \ *OFFSPRING*	0·0–0·9	1·0–1·9	2·0–2·9	3·0–3·9	4·0–4·9	5·0–5·9	6·0–6·9	7·0–7·9	8·0–8·9	9·0–9·9	10·0–10·9	11·0–11·9	12·0–12·9	13·0–13·9	14·0–14·9	15·0–15·9	16·0–16·9	17·0–17·9	18·0–18·9	19·0–19·9	20·0–20·9	21·0–21·9	22·0–22·9	23·0–23·9	24·0–24·9	Totals
0·0–0·9	14	8	2	4	4	9	1	6	3	2	4	2	1	2	3	2	2	1	1					2		73
1·0–1·9																										
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4·0–4·9																										
5·0–5·9																										
6·0–6·9	1					2		2	1		1	1		1			1						1			11
7·0–7·9																										
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16·0–16·9																										
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18·0–18·9	2	2	1			1			1	2	2	3	1			1	2			1						19
19·0–19·9																										
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27·0–27·9																										
28·0–28·9				1	1			2	1	1		2	1	2	2	3			2	1					1	20
Totals	20	13	3	5	7	15	2	13	6	5	7	9	4	6	6	7	5	1	3	2			1	2	1	143

Coefficient of correlation = $+0{\cdot}28 \pm 0{\cdot}08$

reliable tests of the significance of the correlation coefficients, reference was made to Fisher [9, Table V A], where it was found that for 143 pairs of variates a correlation coefficient of 0·28 corresponds to a value of $P = 0{\cdot}01$, and for 72 pairs of variates a correlation coefficient of 0·25

corresponds to a value of $P = 0{\cdot}05$. Therefore, the correlation between the kemp-analysis figures for rams and their daughters is significant, but a similar correlation for ewes and their daughters is low. However, undue weight should not be attached to the difference in the levels of significance of the two correlation coefficients, since the number of pairs in the rams' series was almost twice the number of pairs in the ewes' series. Had the number of pairs of variates not differed so widely in the

TABLE 3. *Relationship between Percentage of Kemp in Ewes and Percentage of Kemp in their Offspring*

CORRELATION TABLE

OFFSPRING

EWES	0·0– 0·9	1·0– 1·9	2·0– 2·9	3·0– 3·9	4·0– 4·9	5·0– 5·9	6·0– 6·9	7·0– 7·9	8·0– 8·9	9·0– 9·9	10·0–10·9	11·0–11·9	12·0–12·9	13·0–13·9	14·0–14·9	15·0–15·9	16·0–16·9	17·0–17·9	18·0–18·9	19·0–19·9	20·0–20·9	21·0–21·9	22·0–22·9	23·0–23·9	24·0–24·9	Totals
0·0– 0·9	5	1			1	2			1	1			1		1					1			1			15
1·0– 1·9		1	1	1	2	1								1	1	1			1							10
2·0– 2·9																										
3·0– 3·9											1															1
4·0– 4·9											2															2
5·0– 5·9						1																				1
6·0– 6·9																										
7·0– 7·9																										
8·0– 8·9		1						1							1											3
9·0– 9·9																										
10·0–10·9				1		1					1															3
11·0–11·9												1														1
12·0–12·9				1												1										2
13·0–13·9		1			1	1				1									1						1	6
14·0–14·9									1						1											2
15·0–15·9							1			1				1		1							1			5
16·0–16·9																										
17·0–17·9						3		1	1			1														6
18·0–18·9			1			1										1		1	1							5
19·0–19·9																										
20·0–20·9																										
21·0–21·9												1	1													2
22·0–22·9																										
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Totals	5	4	2	3	4	11	1	2	3	3	6	4	2	3	4	4	2	1	3	2			2		1	72

Coefficient of correlation $= +0{\cdot}25 \pm 0{\cdot}11$

two cases, this might have been regarded as evidence suggestive of sex-linkage. In the absence of recorded male progeny, it is not at present possible to determine whether for kemp-content any influence of sex-linkage inheritance exists. Some preliminary evidence would appear to have been obtained, but until opportunity for further work occurs it is not desirable to stress unduly this aspect of the problem.

The distribution of the kemp-analysis figures in the experimental ewe-flock is given in Fig. 6, which should be read in conjunction with Table 4. There are 320 individual analyses included in the diagram.

It is worthy of note that the breeding sheep on this farm had been selected in such a way that individuals showing a very high proportion of kemp had been eliminated from the stock during some seven years before these investigations were started.

The distribution of the kemp-analysis figures in stud rams belonging to breeders in many parts of Scotland is given in Fig. 7 and Table 4.

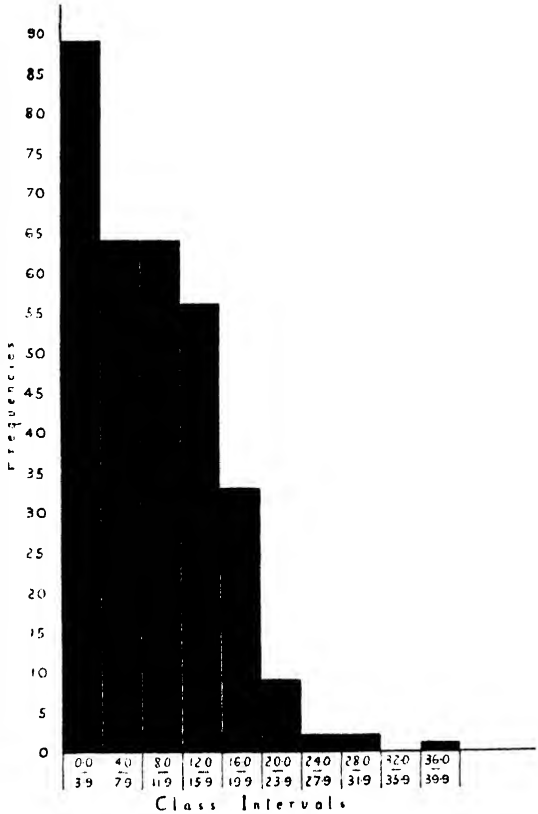

FIG. 6. Distribution of the kemp-percentage figures for the ewe-flock
Mean percentage = $8{\cdot}97 \pm 0{\cdot}37$
No. of individuals = 320

These rams had been carefully selected for breed points, including comparative freedom from kemp. In this respect they were suitable for comparison with the ewe-flock.

From general experience gained during this work, in which visits were made to many Blackface sheep farms in Scotland, and from an examination of large numbers of Blackface ewes, it can be confidently stated that there are few commercial Blackface flocks in which the mean percentage of kemp is so low as that of the stud rams referred to above, or that of the ewe-flock, which was mainly used for the purpose of this experiment.

In Table 4 an estimate is given of an average distribution of kemp in a typical commercial flock. The percentages are necessarily approximate, but an endeavour has been made to avoid assessing the values too highly. This is included solely for purposes of comparison.

The close similarity in the distribution of the kemp-percentage figures

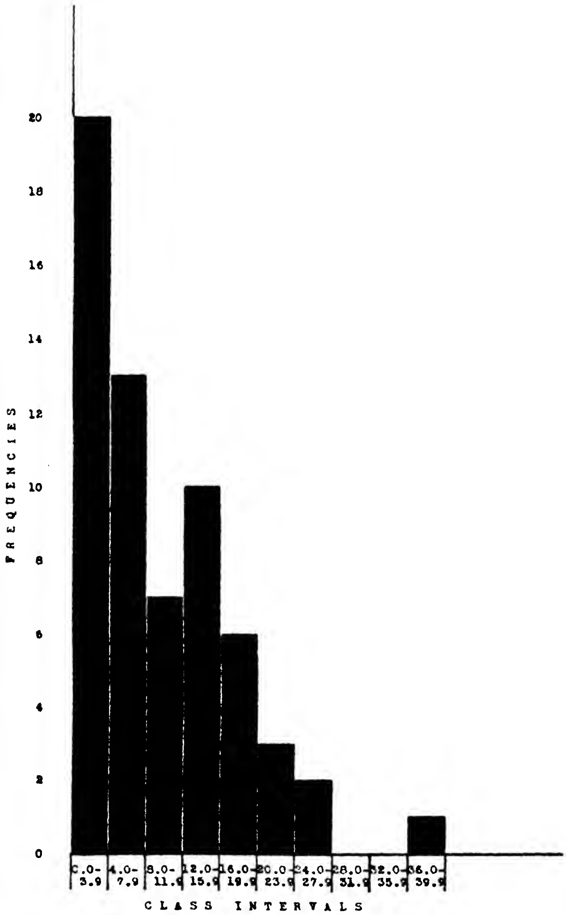

FIG. 7. Distribution of kemp-percentage figures in a group of 62 stud rams
Mean percentage $= 9{\cdot}28 \pm 1{\cdot}03$

in the ewe-flock and in the group of stud rams can be seen from the figures. This is especially noticeable with regard to the first two classes, viz. 0 to 3·9 per cent. and 4 to 7·9 per cent.

In Table 5 and Figs. 8, 9, and 10 the kemp-analysis figures obtained from groups of the female progeny of rams A, B, and C are shown.

Figs. 11, 12 and 13 show similar details for groups of the female progeny of rams D, E, and F. These three rams were disposed of before this work was begun, so that no analysis of their fleeces could be made. The details of the progeny-groups are given here because the distribution

TABLE 4. *Average Distribution of Kemp in Experimental Flock and Estimate for Average Commercial Flock*

	Less than 4%		*4%–7·9%*		*8%–19·9%*		*20% and over*		
	No.	*Percentage of whole*	*No.*	*Percentage of whole*	*No.*	*Percentage of whole*	*No.*	*Percentage of whole*	*Mean kemp per cent.*
Stud rams	20	32·3	13	21·0	23	37·1	6	9·6	9·28±1·03
Flock ewes	89	27·8	64	20·0	153	47·8	14	4·3	8·97±0·37
Estimate for average commercial flock		18·0		16·0		50·0		16·0	

of the kemp-percentage figures for each group shows considerable divergence from that of the ewe-flock. Reference to the figures and to Table 5 shows that the kemp-figures of the progeny of rams D and E were distributed similarly, but the progeny of ram F were considerably more kempy, 75 per cent. having kemp-percentages of from 8 to 19·9 per cent. On the assumption that the ewe-groups selected for each ram during the years he was used represented a random sample of the ewe-flock as a whole—no conscious selection either for or against kempiness having been carried out in the particular matings involved—the kemp-analyses of the six progeny-groups clearly indicate that different rams transmit widely different kemp-contents to their offspring. It is extremely unlikely that the differences in kempiness shown by the various progeny groups, when compared with those of the whole ewe-flock, could have arisen by chance; and it is even more unlikely that the wide divergences displayed by the progeny of rams A, B, and F were accidental or coincidental.

TABLE 5. *Average Distribution of Kemp in Female Progeny of Rams*

	Less than 4%		*4%–7·9%*		*8%–19·9%*		*20% and over*		
Progeny of:	*No.*	*Percentage of whole*	*No.*	*Percentage of whole*	*No.*	*Percentage of whole*	*No.*	*Percentage of whole*	*Mean kemp-percentage*
Ram A (kemp analysis < 1%)	21	46·7	11	24·4	11	24·4	2	4·4	6·19±0·91
Ram B (kemp analysis 28·9%)	1	3·3	3	10·0	15	73·3	1	13·3	15·40±1·14
Ram C (kemp analysis 18·3%)	5	26·3	1	5·3	13	68·4	..	..	9·25±1·31
Ram D (not sampled)	9	19·6	7	15·2	27	58·7	3	6·5	10·63±0·98
Ram E (not sampled)	6	16·2	7	18·9	21	56·7	3	8·1	10·88±1·23
Ram F (not sampled)	2	10·0	2	10·0	15	75·0	1	5·0	13·69±1·24

In Table 6 the usual test for the significance of the difference between two means is applied for the difference between the mean kemp-percentage of each progeny-group and the mean kemp-figure of the ewe-flock.

It will be noted that the difference is clearly significant in the case of the progeny of rams B and F, and closely approaches significance for the

TABLE 6. *Significance of the Difference between the Means of the Kemp-percentage Figures of the various Progeny Groups and the Mean Kemp-percentage in the Ewe-flock*

Progeny of:	*Mean kemp-percentage figure*	*D—difference from mean kemp-percentage of ewe-flock*	*S.E.$_D$—standard error of the difference*	$\frac{D}{S.E._D}$
Ram A	6·19	2·78	0·98	2·82
Ram B	15·40	6·43	1·20	5·35
Ram C	9·26	0·28	1·37	0·21
Ram D	10·63	1·65	1·04	1·59
Ram E	10·88	1·91	1·28	1·49
Ram F	13·70	4·72	1·29	3·65

progeny of ram A, but there is no indication of significance for the progeny-groups of rams C, D, and E. It would seem that these three rams, and especially ram C, were unable to influence the kemp-content of the fleeces of their progeny to the degree exhibited by, for example, ram B.

In Table 7 the kemp-analyses of rams G, H, J, K, and L, and some of their female progeny, will be found. Since the number of progeny-analyses available for each of these rams was small, and since the five rams had the same kemp-figures, the kemp-percentages of their progenies

TABLE 7. *Kemp-percentage Figures of the Progeny of Rams G, H, J, K, and L*

	Kemp-percentage figures of progeny
Ram G (kemp-percentage < 1)	10·56 14·99
Ram H (kemp-percentage < 1)	1·32 4·56 5·27 5·50 5·61 7·35 7·92 9·36 10·56 15·21 15·48 16·86 18·35 Mean = 9·53 ± 1·44
Ram J (kemp-percentage < 1)	< 1 2·94 5·52 7·75 8·89 14·76 Mean = 6·72 ± 1·86
Ram K (kemp-percentage < 1)	< 1 1·13 5·28
Ram L (kemp-percentage < 1)	< 1 8·32 11·21
	Mean of Group = 8·01 ± 1·01

were combined in a composite diagram, Fig. 14, in which the distribution of the kemp-percentage figures for the whole group is shown. By comparison with the kemp-figures for the ewe-flock (Fig. 6) it will be observed that whereas a smaller proportion of the group under discussion had kemp-percentages of less than 4, appreciably more had analyses of less than 8 per cent.; 55·5 against 47·8 per cent. in the ewe-flock. Compared with the progeny of ram A (Fig. 8), the present group appears to be definitely more kempy. Reference to Table 7 shows, however, that the mean kemp-percentage is 8·01 ± 1·01. It is evident that there is no

significance in the difference between this mean and the mean kemp-figure of the progeny of ram A.

In Fig. 15 particulars are given of the kemp-analysis figures of 57 groups of sire, dam, and offspring. In the diagram the matings of each

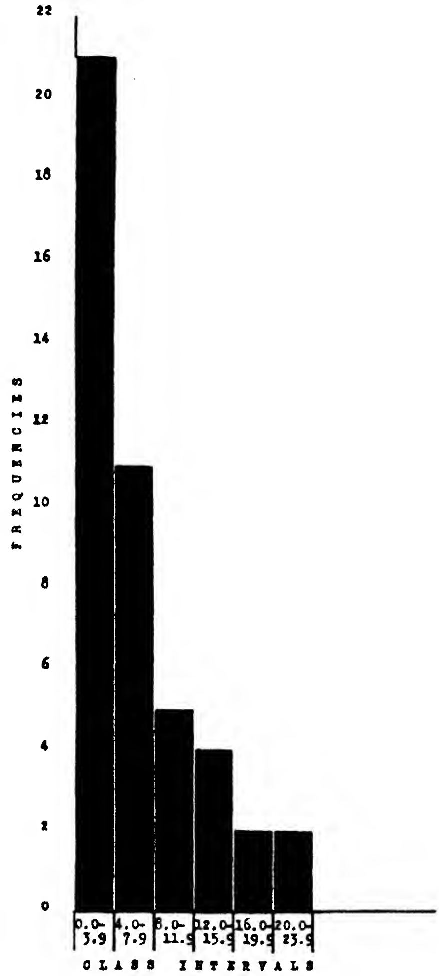

Fig. 8. Distribution of the kemp-percentage figures in 45 of the female progeny of ram A, which itself had less than 1% of kemp

Mean percentage = $6{\cdot}19 \pm 0{\cdot}91$

individual ram are separated by a horizontal line. The kemp-analyses of 10 rams, ewes to which they were mated, and the resulting female offspring are shown.

In the first case the ram (ram A) had an analysis of less than 1 per cent. and figures are given for 15 individual matings. It will be noted that four of the progeny (or 26·6 per cent.) had kemp-figures of less than 4 per cent., and 10 (or 66·6 per cent.) had analyses of less than 8

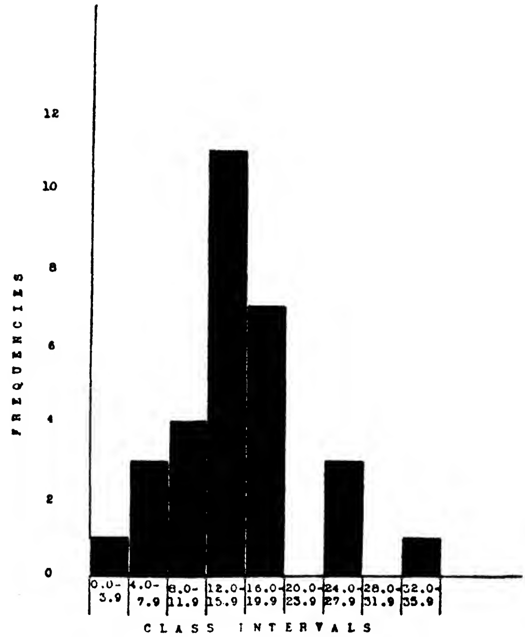

FIG. 9. Distribution of the kemp-percentage figures in 30 of the female progeny of ram B, which showed 28% of kemp

Mean percentage = 15·40 ± 1·14

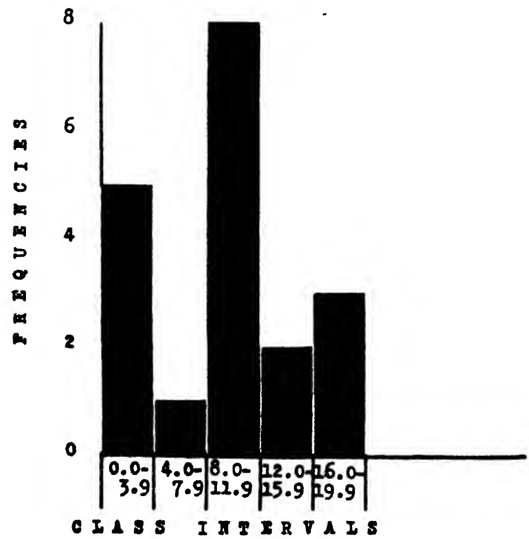

FIG. 10. Distribution of the kemp-percentage figures in 19 of the female progeny of ram C

Mean percentage = 9·25 ± 1·31

per cent., so that only 5 daughters (or 33·3 per cent.) had kemp-analyses of more than 8 per cent. Further, 9 of the progeny (or 60·0 per cent.) had kemp-figures identical with those of their parents, or intermediate between those of the sire and dams, and 6 (or 40 per cent.) had kemp-figures exceeding those of their parents.

In the second largest group of matings, those of ram B, with a kemp-analysis of 28·98 per cent., only 1 of the progeny (or 7·7 per cent.) had

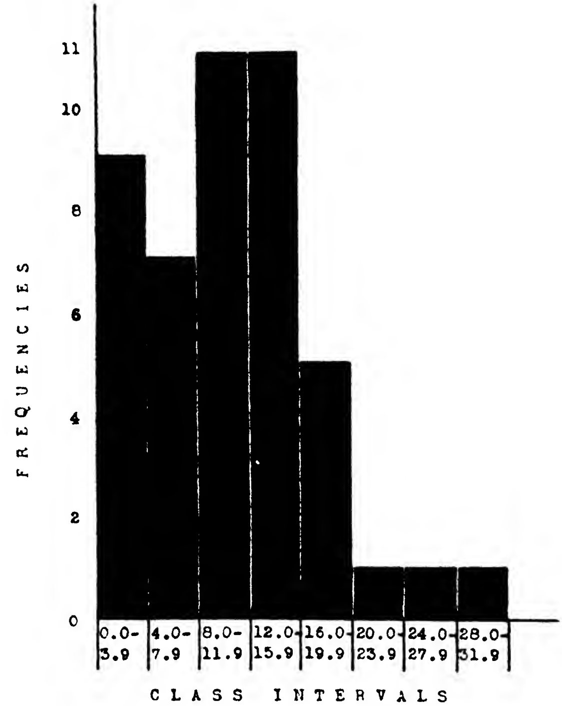

FIG. 11. Distribution of the kemp-percentage figures in 46 of the female progeny of ram D
Mean percentage = 10·63±0·98

a kemp-analysis of less than 4 per cent., and 2 (or 15·4 per cent.) had kemp-figures of less than 8 per cent. Thus 11 daughters (or 85·4 per cent.) had over 8 per cent. of kemp in their fleeces. Eight of the progeny (or 61·5 per cent.) had kemp-values identical with those of their dams or intermediate between those of their parents, while 5 (or 38·5 per cent.) had figures below those of both parents.

These analyses provide further evidence of the tendency shown by these rams in previous data (Figs. 8, 9) to transmit to their offspring a specific degree of kempiness.

The numbers of matings recorded of the other eight rams are too small to indicate the degree to which each transmitted its expression of kemp to its offspring. It should be noted, however, that in 18 of the 29 matings (62·1 per cent.) of these rams, the offspring had kemp-analyses identical with that of one of their parents or intermediate

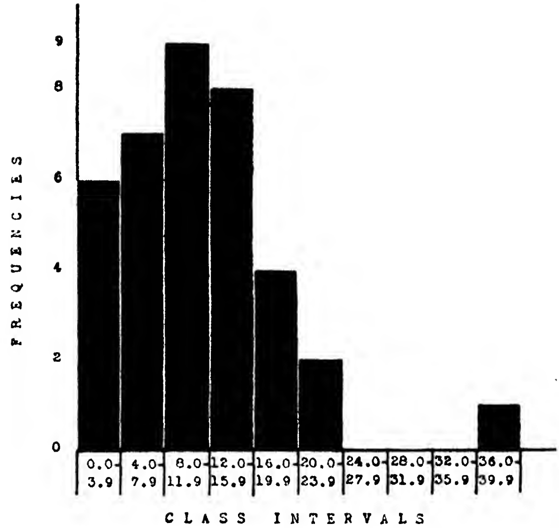

FIG. 12. Distribution of the kemp-percentage figures in 37 of the female progeny of ram E

Mean percentage = 10·88 ± 1·23

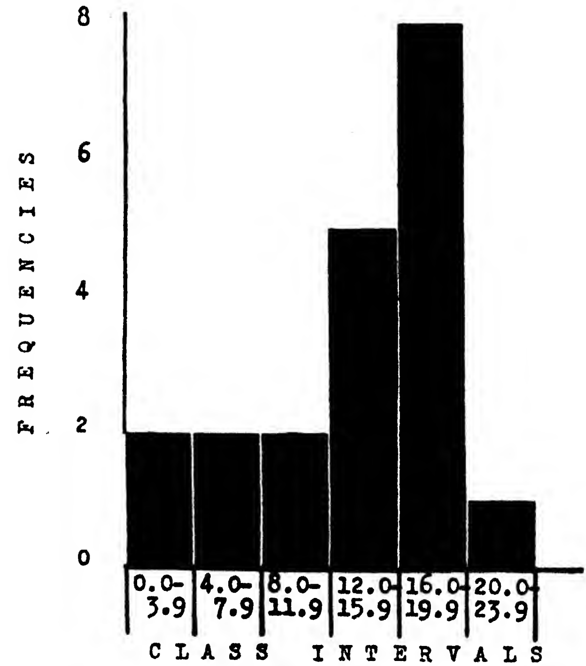

FIG. 13. Distribution of the kemp-percentage figures in 20 of the female progeny of ram F

Mean percentage = 13·69 ± 1·24

between their parents' analyses. Finally, out of the whole series of matings, in 35 cases (61·4 per cent.) the progeny had the same kemp-analysis as one of their parents or analyses intermediate between those of their parents.

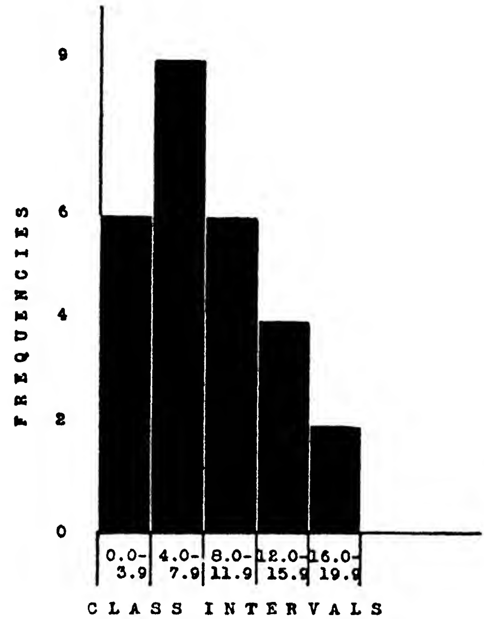

FIG. 14. Distribution of kemp-percentage figures in the progeny of rams G, H, J, K, and L, each of which had kemp-analysis figures of < 1%

Mean percentage for group = 8·01 ± 1·01

Discussion

In searching the literature, the writer has not found any published account of investigations on the inheritance of kemp carried out by analysing a large number of fleeces of adult sheep in a recorded flock. Roberts [3] states that in the majority of cases in the Welsh Mountain breed, the percentage of kemp in the adult fleece is correlated with the type of birthcoat, and that non-kempy adult fleeces correspond to a type of covering in the lamb which is definitely unsuitable for mountain conditions. Barker [10], reviewing Roberts's work, states that the type of birthcoat exhibited by the lamb is governed by heredity. He does not, however, quote any scientific proof of this. White [11] refers to the relationship between kemp in the adult Welsh fleece and the type of coat of the lamb. He states further that the type of birthcoat was found to be inherited, and that more than one factor is concerned. These authors have not published data, so far as the writer is aware, which demonstrate the mode of inheritance of kemp in the Welsh Mountain breed. Darling [2] investigated the wool–long-hair–kemp relationships in a number of selected Blackface sheep. He found that the range

of variability of kemp was very great and deduces from this that kemp could be bred out of the fleece. Barker [10] alludes to the opinion held by many experienced breeders, that the presence of kemp is governed by hereditary factors. The writer has met breeders of Blackface sheep who were convinced that kemp could be practically eliminated from the breed by judicious selection of breeding-stock. Personal opinions, however, even when based on much practical experience, do not constitute scientific evidence, and of this there appears to be an almost complete absence.

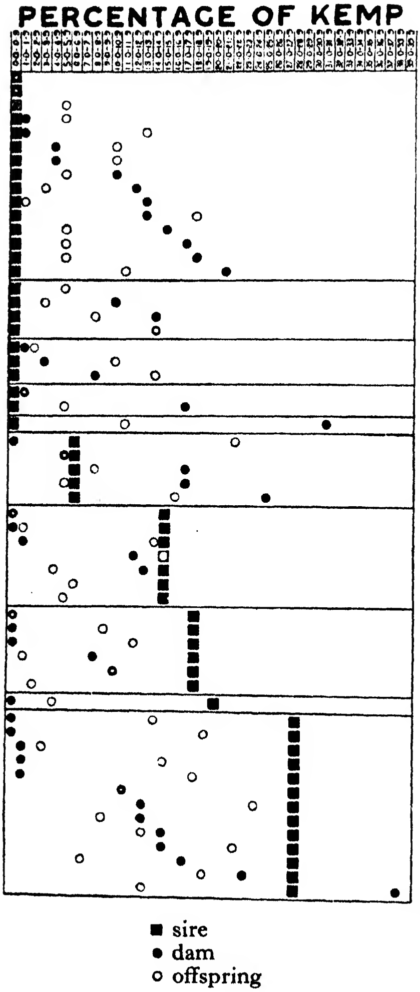

FIG. 15. Diagrammatic representation of the kemp-analysis figures of sire, dam, and offspring in matings of 10 rams

■ = sire, dam, and offspring
■ = sire and dam
□ = sire and offspring
● = dam and offspring

The literature contains many references to cross-breeding experiments made, in many cases, with a view to producing an improved type of fleece by the use of fine-wooled rams on ewes of coarse-wooled breeds.

Dechambre [12] found that the offspring from the cross between a medium fine-wooled Berrichon ewe with a hairy-coated African fat-tailed ram had hairy coats like that of the sire. Ewart [13] mated Blackface ewes to a Southdown ram. He found there was considerable variation both in body-conformation and in fleece-characters in the F_1 and F_2 generations, but all the progeny resulting from this cross were free from kemp. Völtz [14] crossed ewes of the Pomeranian land breed with an Oxford ram. He reports that the mixed wool of the former (which contains kemp) is dominant over the Oxford-down type of wool. Spöttel [15] found that in the F_1 generations of crosses between Moufflon and Somali sheep with Merinos, a kempy type of fleece predominated, and that other fleece-characters in the F_1 were intermediate between the Moufflon or Somali and the Merino. He states further that in the F_2 generation kempiness predominates at first, but a gradual refinement occurs with advancing age. Ivanov, Belekhov, and Greben [16] in the F_2 generation from crosses of Voloshian and Chuntuk ewes with Lin-

coln rams, observed no segregation of fleece-characters. They state that the F_2 resembles the F_1, that there was intermediate inheritance of fleece-characters, and that in the F_2 from Chuntuk ewes none of the Chuntuk characters, such as coarse hair or kemp, were found. Among other Russian work dealing with the inheritance of fleece-characters in crosses are papers by Belekhov [17], [18], Belekhov and Greben [19], and Ivanov and Belekhov [20]. These are all concerned with the crossing of coarse-wooled breeds with Merinos. Kemp fibres were not found in either the F_1 or the F_2 generations, but there was a more marked segregation of characters in these crosses than was found, for example, in the Lincoln × coarse-wooled crosses. In summing up, the suggestion is made that the number of factors involved in the Merino crosses is smaller.

The examples quoted of observations on the occurrence of kemp fibres in crosses between non-kempy and kempy breeds of sheep indicate that, if kempiness be inherited, the inheritance is not of a simple Mendelian type, but is probably governed by multiple factors. It is doubtful, however, whether analyses of kempiness in interbreed crosses have any place in a survey of the incidence of kemp in a pure-bred flock such as the present work.

It might be argued that this investigation has not been conducted on correct genetical lines; that ewes and rams should have been sampled at the appropriate time and samples obtained from their progeny when these became adult. It is admitted that this would have been the ideal procedure, but it is emphasized that the best use had to be made of the material available in a limited time. Further, the flock of sheep which provided the bulk of the experimental material was managed on strictly commercial lines, and it was not possible to interfere with the ordinary farm routine.

It is claimed that the data produced establish beyond doubt the fact that the presence of kemp fibres in the fleece of the Blackface sheep is definitely controlled by heredity. If this were not so, the distribution of the kemp-percentage figures for the progeny-group of each of the rams would be expected to approach that of the whole flock. This has been shown not to be the case.

The ages of the experimental sheep varied between 1½ and 4½ years, and this might be thought to constitute a source of considerable error in comparisons of kemp-content. No evidence was found, however, to show that the percentage of kemp in individual sheep varied to any appreciable extent between these ages. Darling [2] showed that with advancing age the percentage weight of long hair decreases and the percentage weight of wool increases. He produced figures for groups of Blackface rams of different ages as shown on the following page.

It will be seen that the figures for mean percentage-weight of wool and long hair together are extraordinarily constant over the five age-groups both for shoulder samples and haunch samples. These figures represent the mean percentage-weight of the non-kemp fractions of the samples, and indicate that decrease in the percentage-weight of long hair with advancing age is balanced by the increase in the percentage-weight of wool. The writer has observed that sometimes very old sheep

show a complete absence of long hair, thus upsetting the ratio of non-kemp to kemp. Although this seldom occurs till sheep reach a very advanced age (over 10 years), it was thought advisable to restrict the analyses to sheep not over 4½ years old. Barker [10] states that 'individual sheep examined over a period of years do not show any large differences between the proportions of kemp in different years', thus confirming the findings below.

Distribution and Percentages of Wool and Long Hair in Blackface Rams (Darling)

		Mean percentage-weight of wool	*Mean percentage-weight of long hair*	*Mean percentage-weight of wool and long hair together (the non-kemp fraction)*
Shoulder staples	Shearlings	40	57	97
	2-shear	47	50	97
	3-shear	48	48	96
	4-shear	48	50	98
	aged	53	44	97
Haunch staples	Shearlings	34	59	93
	2-shear	36	56	92
	3-shear	38	50	88
	4-shear	41	49	90
	aged	44	48	92

The influence of factors other than genetic on the expression of fleece-characters involves a wide field of investigation. This work, however, is not intimately concerned with such influences, since all the experimental sheep, with the exception of breeders' stud rams, were kept on the same farm under the same climatic conditions, and all shared the same grazing-land. It is not the practice on the farm in question to feed the stock rams intensively. These are kept out day and night until a few weeks before they are mated to the ewes, when they are brought into the house each evening and fed moderately well till they are allowed to run with the ewes. This brief period of hand-feeding has no appreciable effect on the expression of kempiness in the fleece. Not less than 3–4 months' feeding are required to effect any marked change in the length or diameter of a kemp fibre in such a way as to cause material change in the percentage of kemp to total wool-substance produced.

It is clear from the results obtained that the expression of kemp in the fleece of Blackface sheep, as measured by the percentage weight in the dorsal area of maximum density, is not controlled by a simple Mendelian type of inheritance. This statement is not, perhaps, justified with reference to the progeny groups of the various rams, where kemp-analyses of the dams were not available. By reference, however, to the kemp-analysis figures for rams, ewes, and the resulting offspring in 57 matings, shown in Fig. 15, it is evident that neither the non-kempy condition shown by the first 5 rams, nor the grossly kempy condition shown by ram B, behaves as a Mendelian dominant. The figures obtained from these matings, in fact, clearly indicate intermediate inheri-

tance governed by multiple factors. Further reference to Fig. 15 will show that out of 25 matings of rams with kemp-analyses of less than 1 per cent., in 15 cases (60·0 per cent.) the progeny had kemp-figures of less than 8 per cent. Similarly, in 32 matings of rams with analyses ranging from 6 to 28 per cent. the progeny in 12 cases (37·5 per cent.) had kemp-percentages of less than 8 per cent. Again, it will be found that the number of ewes with kemp-analyses of less than 4 per cent. in this series is 22. Of these 12 (or 54·5 per cent.) had progeny with kemp-figures of less than 8 per cent. To consider the figures for these ewes in another way: there were 9 ewes with analyses of less than 4 per cent. of kemp mated to rams with kemp-figures of less than 1 per cent. Of these 7 (or 77·7 per cent.) had progeny with kemp-analysis figures of less than 8 per cent. There were mated to the other rams (kemp-analyses ranging from 6 to 28 per cent.) 13 ewes with kemp-percentage figures of less than 4 per cent. In only 5 cases (38·5 per cent.) did the resulting progeny have kemp-percentages of less than 8. The above figures would appear to indicate that the non-kempy condition of the fleece in the Blackface sheep is incompletely dominant over the more kempy condition. This is supported by the breeding performances of rams A, G, H, J, K, and L, as illustrated in Figs. 8 and 14.

If, then, the presence of kemp in Scottish Mountain Blackface sheep is inherited intermediately, with a tendency for non-kempiness to be dominant, eradication or reduction to negligible proportions is within reach of the practical breeder by the use of rams with fleeces of very low kemp-content, in conjunction with the rigid rejection for breeding of grossly kempy offspring. The level of kempiness tolerated in the offspring would be decreased each season. It is thus theoretically possible to establish an almost kemp-free flock in the course of a very few generations, provided an adequate supply of rams with a low kemp-content in the fleece and of good breed-type be available. It would probably take longer in practice, however, since many points other than kempiness must be considered when selecting breeding-stock, such as body-conformation, size, colour, &c.

There appear to be no great obstacles, however, to prevent breeders of Scottish Mountain Blackface sheep from first reducing by considerable proportions, and then practically eliminating, kemp fibres from the fleeces of their sheep by intelligent selective breeding, together with rigid culling of all sheep showing reversions to the kempy condition.

It seems probable that it would be extraordinarily difficult to eliminate kemp entirely from Blackface sheep. During the examination of wool samples from some 600 sheep in the course of this work, samples from the dorsal area of only one animal were encountered which contained no kemp. Each sheep among the large number classed as containing less than 1 per cent. contained a few typical kemp fibres, though it was always possible to obtain samples from the shoulder region of sheep in this class which were entirely free from kemp. If the incidence of kemp in this breed were to be reduced to such negligible proportions, however, the remaining few fibres would not be a serious objection.

In a genetic experiment involving the analysis of samples of wool, the time which must elapse before samples can be secured from progeny prevents rapid accumulation of evidence, since the sheep is essentially a slow-breeding animal. Under ideal conditions the future development of this work should follow a method which would aim at first establishing a family of sheep (rams and ewes) as nearly homozygous for absence of kemp as possible. Similarly, a definitely kempy strain would be evolved. To effect this would probably take 6–8 years of controlled breeding. Not until this has been carried out with success could reciprocal matings between kempy and non-kempy individuals be made with a view to determining what mode of inheritance is involved in the transmission of kemp; similarly the question of any influence of sex-linkage must await facilities such as are outlined above before it can be determined.

Conclusions

1. The presence of kemp fibres in the fleeces of Scottish Mountain Blackface sheep is inherited.
2. The type of inheritance is that known as Intermediate Inheritance, depending upon a multifactor basis. No form of simple Mendelian inheritance is sufficient to accommodate the results obtained.
3. The lower degrees of kempiness encountered show a tendency to behave as partial or incomplete dominants over the varying higher degrees of kempiness.
4. The presence of kemp could be reduced to negligible proportions by the use of homozygous non-kempy breeding rams, and ruthless culling of kempy progeny.
5. It is improbable that absolute elimination of kemp could be achieved.

Acknowledgements

The writer desires gratefully to acknowledge his indebtedness to Prof. F. A. E. Crew for granting facilities for the carrying out of this work. His sincere thanks are extended to Prof. Wm. C. Miller, who kept in constant touch with the investigations and gave much helpful advice; to Dr. J. A. Fraser Roberts, who allowed him free access to unpublished data and offered advice on the interpretation of the results obtained; to Dr. O. J. Robison, who afforded him much assistance in checking calculations; to Dr. I. W. Parnell for help in the collection of samples; to the many breeders who placed their sheep at his disposal, and in particular to the owner of the recorded sheep who made it possible to arrive at conclusions so rapidly; and also to Miss M. V. Cytovich, of the Imperial Bureau of Animal Genetics, for the translation of Russian papers.

The expenses incurred in this work were met in part by the Empire Marketing Board and in part by the Carnegie Trust; during the investigation the writer held a Carnegie Research Scholarship, and wishes to express his gratitude for the opportunities thus afforded him.

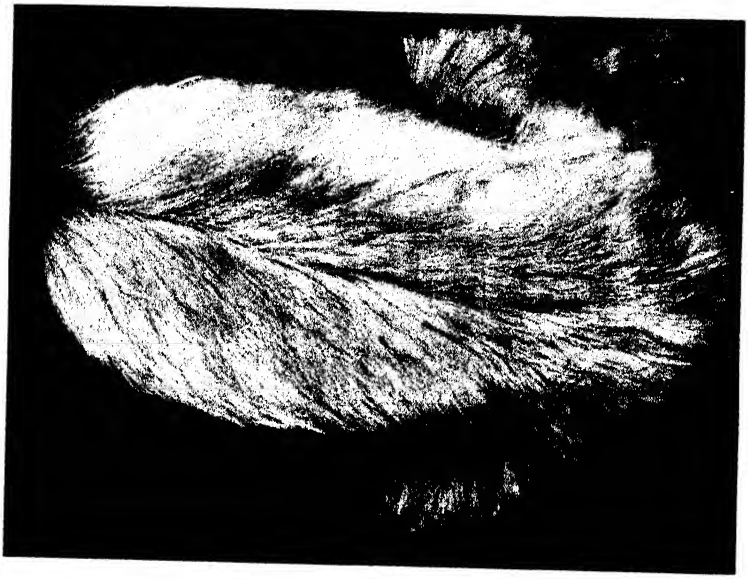

FIG. 2. Carcass of Blackface ewe, to show the kempy patch over the dorsal region after removal of wool and long hair.

FIG. 3. Carcass of Blackface ewe, showing well-defined margin of dorsal kempy area. The drawing-pins indicate the position of the last four ribs.

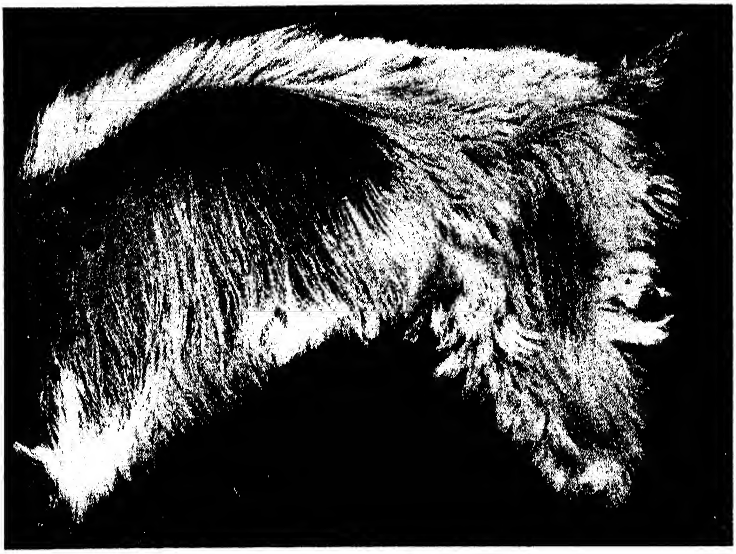

FIG. 4. Carcass of Blackface ewe, showing the dorsal kempy area, and the distribution of kemp over the flank and lower parts of the abdomen.

FIG. 5. Carcass of Blackface ewe, showing the beginning of the dorsal kempy area and the absence of kemp on the thorax. The drawing-pins indicate the line of the spine of the scapula, the last four ribs, and the posterior edge of the last costal cartilage.

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(t.t. = translated title.)

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STUDIES ON REPRODUCTION IN CATTLE

Pt. I. THE PERIODICITY AND DURATION OF OESTRUS

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It has been observed that Zebu cattle in East Africa appear to exhibit a seasonal fertility, in that fertile matings tend to occur more particularly at a certain season of the year (unpublished results). It seemed that this apparent seasonal fertility could best be explained by assuming that conditions for the occurrence of oestrus and ovulation were more favourable at this time of the year than at any other. Considerable variation in the duration and intensity of oestrus is known to occur, and Hammond [1], working under experimental conditions, noted that in Britain the average duration of oestrus is longest in the summer months and shortest in the winter months.

Observations were accordingly undertaken, first, to ascertain if significant variation in the duration of oestrus in Zebu cattle did occur from season to season, and secondly, to investigate the relationship of any such variation in the duration of oestrus to seasonal variation in environmental conditions.

Experimental Material and Methods

In order that all seasonal changes be noted, as complete a record as possible was kept of environmental conditions, coincident with the observations on the oestrous cycle. Meteorological records—rainfall, maximum and minimum temperatures, and, as no sunshine-recording apparatus was available, observations on the amount of cloud—were made daily. Monthly analysis of the pasture was very kindly undertaken by Prof. R. G. Linton.

All the observations were made on a stock-farm in North Kavirondo in Kenya Colony. The farm is situated approximately 50 miles north of the equator (0·31° N. and 34·30° E.) at an altitude of about 4,900 ft. above sea-level. Normally there are two rainy seasons in the year: the long rains occur approximately from March to June, and the short rains in August, September, and October. The average annual rainfall for this district, recorded at two stations for 11 and 8 years, respectively, is 68·41 in. The wettest months of the year are March (av. 6·11 in.), April (av. 9·15 in.), May (av. 9·58 in.), June (av. 6·02 in.), August (av. 8·96 in.), and September (av. 6·37 in.). July with an average rainfall of 5·94 in. is the driest month between the long and short rains. January with an average of 2·26 in. is the driest month of the year, closely followed by November, December, and February. No temperature records are available for this district as a whole, but those from an adjoining district (recorded at a station approximately 50 miles from the above stock-farm and at a slightly higher altitude) show that the maximum and minimum temperature range for the year is comparatively

slight. The mean of maximum and minimum temperatures for 1931 was 73·4° F. and 50·3° F., respectively; the absolute maximum temperature was 83·0° F., and the absolute minimum temperature was 43·1° F.

Originally 11 animals were chosen for the experiment, but for various reasons not connected with the experiment 6 were discarded. Of the 5 animals that were used for the observations on the oestrous cycle, 2 were cows and 3 were heifers. The cows had each borne one calf, but neither was milking during any period of the time they were under observation. The average ages of the cows and heifers were $4\frac{1}{2}$ and 3 years, respectively. All 5 animals gave a negative reaction to the contagious-abortion test at the beginning of the experiment.

The experiment proper began in March 1933. It had been intended to regard the period March–April as a preliminary period and to begin the experiment in May, but unforeseen circumstances necessitated finishing the experiment in February 1934; experimental details are, however, given from March in order that a complete year may be covered. There are, moreover, no reasons why data from the period March–April should not be considered with the rest of the data. From March until the end of April two vasectomized bulls were used. The procedure adopted at this time was as follows: after a bull had served a cow he was removed from the paddock and immediately replaced by the other bull. This bull was removed in 30 min. or on service, whichever was the lesser period, and the other bull was returned. This procedure was continued until the end of oestrus. On a few occasions when a further service had not taken place in 30 min., the bull was left with the cow until service occurred, or indefinitely when no service took place. It was noted that on three occasions bull No. 22 failed to serve an oestrous cow although with her for 30 min., and on another occasion bull No. 21 did not serve an oestrous cow although with her for well over an hour. As the duration of oestrus seemed to be very short it was decided to use only one bull for further observations, and from May onwards bull No. 21 was used, except for a few occasions when two cows coming on 'heat' at about the same time necessitated the use of both bulls, and in November when bull No. 21 was suffering from phimosis and was unfit for service. As both bulls had several times been observed to take a long time to serve a cow on 'heat' the following procedure was adopted and used from May until the end of the observations in the following February. The 5 experimental animals were kept with the vasectomized bull in two paddocks, each of which was approximately four acres in extent. The animals were moved from one paddock to the other according to the state of the grazing. Owing to the scarcity of grazing during the dry season (December, January, and February) the animals were allowed to graze outside, but in the neighbourhood of the paddocks. Once a day the animals were watered at a stream half a mile away. Since the bull was with the cows all the time, a cow was noticed immediately she began to show signs of coming on 'heat'. If this occurred during the day the oestrous cow was allowed to remain with the rest of the experimental animals, but if at night, the cow was placed in a small paddock adjoining the larger ones for ease of observa-

tion. The approximate date on which a cow was due to come on 'heat' was known from previous records. If a cow had not come on heat by the seventeenth day after the beginning of the previous oestrous period she was placed in the small paddock that night and kept under observation night and day until she did. The exact time of the initiation of oestrus was thus known.

The bull was removed from the cow immediately after service had taken place. After half an hour he was put back with the cow and left with her, either until a further service took place, in which case he was again removed for half an hour, or indefinitely when no service occurred. In this way there was no possibility of service not taking place through the bull being with the cow for too short a time. The greatest number of services performed by bull No. 21 within a short period—5 in 6 hours and 8 in 28 hours—took place when 3 cows came on 'heat' within a day of each other. This number of services appeared to have no adverse effect on the sexual capabilities of the bull. Throughout the experiment bull No. 21 performed 124 services and bull No. 22 27 services. Oestrus was recognized solely by the occurrence of mating, and the duration of oestrus was estimated as the time between the first and last service in the one oestrous period. External signs of oestrus were usually so slight as to be unrecognizable. Occasionally a flow of mucus, at first clear and fairly fluid, later thicker and whitish, occurred at the time of oestrus. An animal coming on 'heat' was easily recognized by the bull following her about, standing near her, and from time to time, particularly as the onset of oestrus approached, attempting to mount her. The duration of the dioestrous cycle was taken as the interval between the beginning of one oestrus and the beginning of the subsequent oestrus.

The Periodicity of Oestrus

It is usually considered that the dioestrous cycle in cattle lasts for approximately 21 days. Hammond, who investigated 58 cycles, using a vasectomized bull, found the range of variation to be from 16·6 to 24·0 days; the mean was 19·2 days and the mode 17·8 days. Frei and Metzger [2] give a slightly greater range of variation, namely, 15 to 25 days. In their investigations the mean was 20·2 days and the mode 19·1 days.

Particulars of the duration of the dioestrous cycle, noted by different workers, are summarized in Table 1. A range of variation exceeding that of 15–25 days may possibly in some instances be due to individual differences, but very extreme variation in the length of the cycle is undoubtedly due to the inclusion of abnormal cycles. It will be seen from Table 1 that the mean length of the cycle, as observed by different workers, lies between 19 and 21 days, and the mode in those cases in which it can be accurately determined between 17·8 and 20·8 days.

Sixty-three cycles in 5 animals were investigated by the author. Details of these cycles are given in Table 2. The range of variation in the duration of the cycle is from 17·9 to 24·1 days; the mean duration is 20·1 days and the mode 20·7 days. The distribution of the cycles of various durations is given in Fig. 1.

TABLE 1. *Duration of the Dioestrous Cycle*

Breed	*Country*	*No. of animals*	*No. of cycles*	*Range of variation (days)*	*Mode (days)*	*Mean (days)*	*Authority*
Shorthorn	Britain	15	58	16·6–24·0	17·8	19·2	Hammond (1927)
Brown	Germany	..	393	8·0–32·0	20·8	21·7	Wagner (1931)
	Germany	..	59	15·0–25·0	19·1	20·2	Frei and Metzger (1926)
	Britain	11	..	17·2–21·2	19·2	19·1	Marshall (1924)
Zebu	Kenya	5	63	17·9–24·1	20·7	20·1	Anderson
	Germany	38	350	6·0–30·0	18–22	..	Struve (1911)
	Germany	12	93	..	18–24	..	Schmid (1902)
	Germany	..	..	..	21	..	Kupfer (1920)
	Germany	..	..	..	21	..	Zeitschmann (1921)
	Germany	..	..	..	21–8	..	Schmaltz (1926)
	Sicily	..	..	..	22	..	Alongi (1924)
	Italy (Umbria)	..	..	..	22–3	..	,, ,,
	Italy (Umbria)	..	..	..	21–8	..	Sanctis (1926)
	Germany	..	..	17·5–28·0	..	..	Weber (1911)
	France	..	..	..	21	..	Curot (1921)
	Germany	..	..	..	21–8	..	Franck-Albrecht (1914)

TABLE 2. *Duration of the Dioestrous Cycle in hours*
Zebu Animals

No. of animals	*1933*										*1934*	
	Mar.	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*
31	493	528	492	505	521	506	512 519	466	580	479 512	514	510
66		469 472	435		470 474	451	493 430	487 444	457	458 431	441	467
72		455 477			435 446	446 485	432 464	453 444	479	460	487 454	
80					514 506	514		493	494 457	548	542	490
90	464	497		492		473	548 531	479	484 494	549		
Av.	478·5	483	463·5	498·5	480·8	479·2	491·1	466·4	492·3	491	487·6	489
No. of cycles	2	6	2	2	7	6	8	7	7	8	5	3

The mean length of the cycle in Zebu cattle (20·1 days) is slightly greater than the figure given by Hammond for Shorthorn crossbreds in Britain (19·2 days), and the mode is also slightly greater. Both figures, however, are well within the range given for European cattle.

Hammond has noted that cows have a slightly longer oestrous cycle than heifers, the average difference being 11 hours. There is no difference in this respect in the animals examined by the author (Table 3).

TABLE 3. *Duration of the Dioestrous Cycle in Zebu Cows and Heifers*

	No. of animal	*No. of cycles*	*Duration of Cycle in Days*		
			Average	*Min.*	*Max.*
Heifers	72	14	18·8	18·0	20·3
	80	9	21·1	19·0	22·8
	90	10	20·9	19·3	22·8
	Average for heifers		20·3	18·8	21·9
Cows	31	14	21·3	19·4	20·0
	66	15	19·1	17·9	20·4
	Average for cows		20·2	18·7	20·2

The monthly variation in the duration of the cycle is shown in Table 2. The longest cycle—498·5 hours—occurs in June and the shortest in May. During the four months November, December, January, and February the cycle maintains a consistently high level, namely, between 488 and 492 hours.

Hammond found that on the average the cycle was about 40 hours longer in the summer than in the winter or spring. Wallace, on the other hand, states that the cycle is shorter in summer than in winter. Wagner [3] gives the length of the cycle in summer and winter as 22·3 and 22·6 days, respectively.

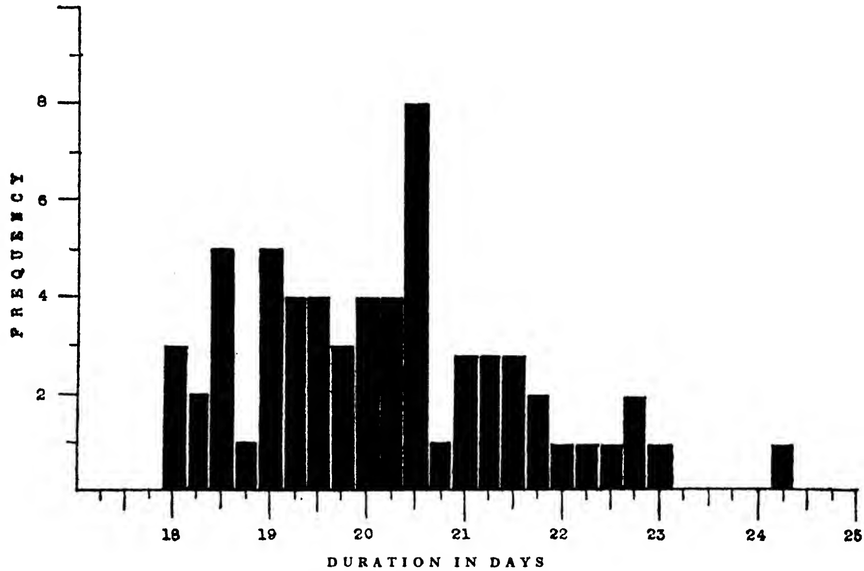

Fig. 1. Dioestrous Cycle

The Duration of Oestrus

Available records show that different workers have noted considerable variation in the duration of oestrus in the cow. It is impossible to say to what extent this is due to the methods employed in determining the existence of oestrus. The signs and intensity of oestrus vary so greatly that they are quite unreliable for this purpose. The only reliable criterion for the physiological and psychological state of oestrus is the occurrence of mating, and it is only by determining over what length of time a cow will accept the bull that the extent of oestrus can be judged.

The mean duration of 64 oestrous periods determined by Hammond in this way was 16·2 hours; the mode was 16·8 hours and the range of variation 6–30 hours. Data on the duration of oestrus in the cow is summarized in Table 4.

The most outstanding feature of the observations made by the author on the Zebu cattle was the extraordinary short duration of oestrus (Table 5). The mean length of 74 oestrous periods was 1 h. 20 min.

In 11 oestrous periods, i.e. in 14·9 per cent. of the total number of oestrous periods, single services occurred. In such cases oestrus was given the arbitrary duration of 10 min. A further check on this point is available from some of the earlier observations when two vasectomized

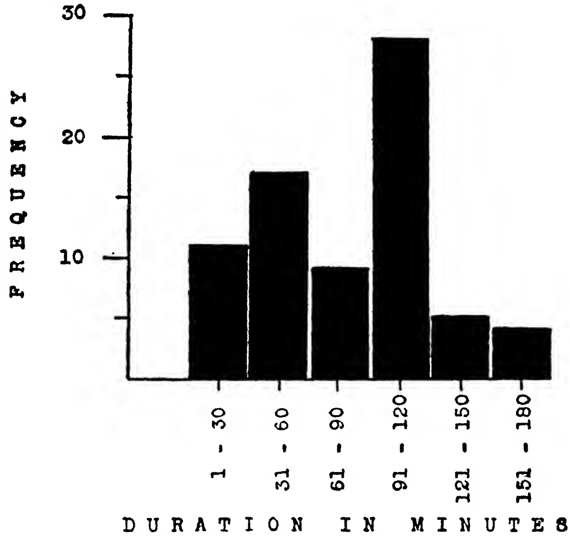

FIG. 2. Duration of Oestrus

bulls were used. At this time the procedure adopted was to remove one bull immediately after service and replace him by the other. On several occasions when this was done no second service took place, a fact which emphasizes the exceedingly brief duration of oestrus. The longest period of oestrus recorded in the 5 animals was 2 hrs. 51 min. Longer periods have, however, been recorded in two other cows, but as these animals

TABLE 4. *Duration of Oestrus*

Breed	*Country*	*No. of animals*	*No. of periods*	*Range of variation (hours)*	*Mode (hours)*	*Mean (hours)*	*Authority*
Shorthorn	Britain	15	64	6–30	16·8	16·2	Hammond (1927)
	Britain	..	12	8–21	16·6	15·7	Marshall (1924)
Zebu	Kenya	5	74	0·2–2·9	1·8	1·3	Anderson
	France	..	..	..	12–24	..	Curot (1921)
	Sicily	..	..	..	24	..	Alongi (1924)
	Italy (Umbria)	..	..	..	12–24	..	,, ,,
	Germany	..	..	..	24–48	..	Franck-Albrecht (1914)
	Germany	..	..	12–120	..	..	Schmaltz (1926)
	Germany	..	155	3–36	..	..	Weber (1911)

reacted positively to the contagious-abortion test data from them have not been included with the other results. In cow No. 12 oestrus lasted for 2 hours and 7½ hours in January and February, respectively, and in No. 41 a period of 5 hours was noted in November, and single services took place in October and January. (There is no record for December in this cow, as the vasectomized bull died of rinderpest.)

TABLE 5. *Duration of Oestrus in minutes*
Zebu Animals

No. of animal	1933										1934		
	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Average
80				10	109	118 99		165 112	60	75	99 106	106	96
72	10	120	46	111	120 135	115 106	141	77 83	81	52 45	100 110		91
90	10	10 38		10 10		10 51	41	148 75	43	95	107	109	54
31	10	10 104	45	90	113	108 171	36	47 97	57	40	152 92	109	80
66	41	10 10	72	62	150	95 97	76 115	147	55 37	158	56 108	104	82
Av. to nearest figure	18	43	54	49	125	97	82	106	55	77	103	107	81
No. of eat-periods	4	7	3	6	5	10	5	9	6	6	9	4	= 74

The shortest duration of oestrus on record seems to be that of Weber [4], who states that in cows with feeble heat-periods oestrus may last 3 hours, but the same author gives the range of variation for such cows as from 3 to 36 hours. Hammond has noted heat-periods of 6 hours' duration and Marshall a period of 8·4 hours. The mean duration of Marshall's and Hammond's figures are 15·7 and 16·2 hours, respectively, and the modes 16·6 and 16·8 hours, respectively. In general the mode has been found by most authors to lie between 12–24 hours. It is therefore the exception for European cattle to have short oestrous periods. On the other hand, in Zebu cattle the mean duration and the mode are 1·3 hours and 1·8 hours, respectively.

Hammond noted that cows have on the average a slightly longer duration of oestrus (19·3 hours) than heifers (16·1 hours); however, when the

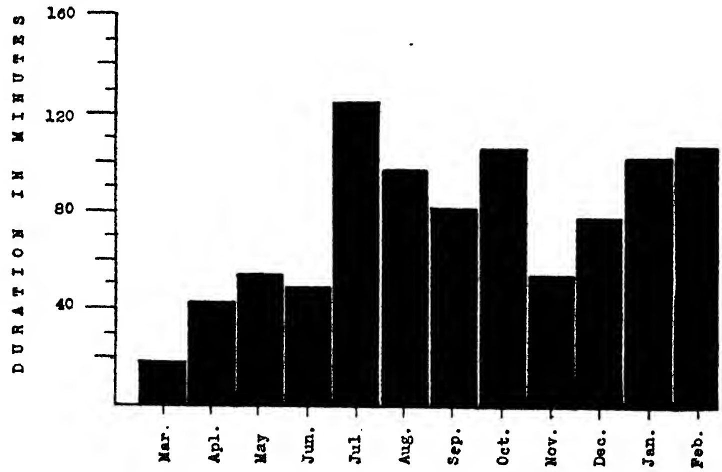

FIG. 3. Monthly Duration of Oestrus

differences in age were slight any effect was masked by individual differences. The difference in age between the Zebu heifers and cows is slight (3 and 4½ years, respectively); the duration of oestrus is similar in both heifers and cows.

The average monthly variation in the duration of oestrus is shown in Fig. 3 (see also Table 5). The average duration of oestrus is longest in

July (2·1 hours), October (1·8 hours), January (1·7 hours), and February (1·8 hours), and is shortest in March (0·3 hours).

Hammond has observed that the average length of oestrus is greatest in the summer months and shortest in the winter months, there being an average difference of 5–6 hours between the two extremes.

There is no evidence that cattle in different European countries exhibit a significant variation in the duration of oestrus. Suitable records are too few, however, to allow of the question being examined critically. Alongi [5] states that, with regard to the duration of oestrus, no significant differences exist between animals in Sicily, Italy (Umbria), and Germany.

Individual differences in the duration of oestrus in Zebu cattle are very slight, which is probably due to the shortness of oestrus in these animals. Hammond found marked individual differences, the heifers varying from 8 to 21 hours and the cows from 17 to 21 hours.

Relationship between Intensity, Duration, and Periodicity of Oestrus

It is a well-known fact that there is considerable difference in the intensity of 'heat' as shown by outward signs in different cows. Intensity is a factor which cannot be measured accurately and is thus liable to considerable error in interpretation. Nevertheless, variation in the intensity of 'heat' does occur. Weber [4] found that oestrus varied from 12 to 36 hours in cows with intense heat-periods, from 6 to 36 hours in cows with average heat-periods, and from 3 to 36 hours in cows with feeble heat-periods. Hammond has noted that during the winter months, when oestrus is short, the signs of 'heat' are slight. They are, moreover, more marked in the summer months when the duration of oestrus is greater. In sheep, Grant [6] has observed that in general long heat-periods were more intense than short ones; in particular the first heat-period of the season was usually shorter and less intense than subsequent periods. In the Zebu experimental animals the signs of 'heat' were scarcely recognizable. This fact is undoubtedly associated with the brief duration of oestrus in these animals.

The experimental data were examined for the existence of a relationship between the duration of oestrus and the duration of preceding and subsequent dioestrous cycles, but, as is shown in Table 6, no such relationship is evident. Hammond, on the other hand, has noted a correlation between the average length of the cycle and the average duration of the subsequent oestrous period, a long cycle being associated with a long oestrous period and a short cycle with a short oestrous period. Grant failed to find a correlation between the duration of oestrus and that of the preceding and subsequent cycles in the sheep; on the other hand he noted a definite negative correlation between the duration of oestrus and the duration of both preceding and subsequent interoestrous periods (i.e. the intervals between the end of one heat-period and the beginning of the next), in that the shorter the period of oestrus, the longer are the preceding and subsequent interoestrous periods. There is no correlation of this nature in Zebu cattle, which may possibly be due to the shortness of the oestrous period in these animals (Table 7).

TABLE 6. *Relation between the Duration of Oestrus and the Durations of Preceding and subsequent Dioestrous Cycles*

Oestrus (min.)	*Preceding cycles*	*Average (hours)*	*Subsequent cycles*	*Average (hours)*
10–39	8	482	13	485
40–69	13	489	13	484
70–99	14	477	12	488
100–29	19	487	15	480
130–59	7	476	7	464
160–89	1	(506)	2	502

In European cattle it is obvious, as Grant [6] has pointed out for sheep, that the interoestrous period is more variable than that of the whole cycle, since it is subject, not only to variation in the length of the cycle, but also to variation in the duration of oestrus. When oestrus is of short duration and the range of variation is not great, as in Zebu cattle, variation in its duration can have little effect on the length of the subsequent interoestrous period. In these animals variation in the length of the interoestrous period is due mainly to variation in the length of the dioestrous cycle.

TABLE 7. *Relation between the Duration of Oestrus and the Durations of Preceding and Subsequent Interoestrous Periods*

Oestrus (min.)	*Preceding interoestrus*	*Average (hours)*	*Subsequent interoestrus*	*Average (hours)*
10–39	8	481	13	485
40–69	13	488	13	482
70–99	14	476	12	486
100–29	19	486	15	479
130–59	6	480	6	465
160–89	1	(504)	2	499

The average length of the dioestrous cycle in British cattle is about 19½ days [1] and in Zebu cattle about 20 days; the mean duration of oestrus in these animals is 16·2 hours and 1·3 hours, respectively. It is therefore clear that a much greater range of variation occurs in the duration of oestrus than in the duration of the dioestrous cycle in the cow.

Summary

1. Records are given of 63 oestrous cycles in 5 animals. The duration of the cycle varied from 17·9 to 24·2 days with the mean of 20·1 days.

2. The mean duration of oestrus was found to be 1 hour 20 minutes.

3. Monthly variation in the duration of oestrus and the oestrous cycle was noted.

4. No relationship was evident between the duration of oestrus and either the duration of preceding and subsequent dioestrous cycles or the duration of preceding and subsequent interoestrous periods.

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STUDIES ON REPRODUCTION IN CATTLE

Pt. II. THE INFLUENCE OF ENVIRONMENTAL FACTORS ON REPRODUCTION

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Within recent years numerous investigations have been made on the relationship of such environmental factors as rainfall, temperature, light, and food, to reproduction, and there is now evidence to show that some of these factors do influence reproduction to some extent.

Effect of rainfall.—Baker and Ransom [1] collected field-mice (*Microtis agrestis*) from different areas over a period of two years, and in an investigation of their breeding-habits failed to find any correlation between breeding and rainfall.

Effects of temperature and light.—Under natural conditions fecundity in both sexes of the field-mouse starts in the coldest time of the year in Britain, namely February–March, and stops when the temperature is still high. Thus temperature would not seem to play an important part in influencing reproduction in this species. On the other hand, under experimental conditions, it was found that a low temperature (about 5° C.) interfered with reproduction in female mice, but the way in which it works is not known [2]. In the rat it has been shown that exposure to cold lengthens the oestrous cycle, and it is thought that this change is brought about through the lowered general metabolic level, since both body-temperature and general activity are reduced [3]. Parkes and Brambell [4] have found that mice kept at 0° C. experience regular oestrous cycles.

Rowan [5] found that artificial illumination in midwinter induced sexual activity in the Junco. Bissonnette [6] found that complete spermatogenesis and maximum testis-size could be induced in 4–6 weeks at any time from December to April in the starling by giving light exposures of 6–7 hours per night, and, conversely, that birds kept in winter light in April, May, and June, when normally in nature the testis attains full reproductive function, did not show any reproductive activity. He showed also that light and not exercise is the responsible factor, for the testis of birds on forced-exercise periods without added light actually became smaller and less active in spermatogenesis. It was, moreover, shown that the degree of stimulation depended on the intensity of the illumination and on the wave-length of the light used. Red light was highly stimulating, but green light of an equal intensity was slightly inhibitory to the activity of both testis and ovary. In the female ferret, on the other hand, Marshall and Bowden [7] found that none of the wave-lengths employed by them caused retardation of the recurrence of oestrus. The recurrence of oestrus in the ferret was greatly accelerated by light of various wave-lengths. Ultra-violet light was the most effective. Green, red, and yellow were also effective in this order.

Infra-red had a slight effect and violet a very small effect, if any at all. The effective radiation extended from red (λ6500) to the near ultra-violet (λ3650), and over this region of the spectrum intensity was more important than wave-length. There was a fairly sharp threshold on the long wave-length end of the spectrum, in that λ7500 was scarcely effective, although its intensity was high, whilst λ6500 gave a marked response.

Bissonnette [6] has found that an increase in the duration and intensity of daily exposures to light induces oestrus in the female ferret whereas reduction in the intensity and period of exposure brings about an anoestrous condition. Hill and Parkes [8] have shown that the effect of additional illumination in inducing oestrus in the ferret in winter depends on the presence of the pituitary body. These workers also found that almost total exclusion of light does not seriously affect the onset of the breeding season in this animal, which is in accordance with the fact that, histologically, breeding changes can be seen in December, long before an increase in the amount of daylight occurs [9]. Hill and Parkes therefore conclude that, whilst additional light will induce oestrus in the anoestrous ferret, the onset of the breeding season in the spring is not dependent on the increasing length of daylight. They prefer to regard anoestrus as merely one phase of the oestrous cycle that is known to depend on some inherent rhythm of the anterior pituitary body. Marshall's criticism of this is that, if there were no external factor involved in the recurrence of oestrus and the problem were merely that of the dioestrous cycle in the mouse, there is no apparent reason why the periodicity of sexual activity in the ferret should so generally conform to that of the seasons. He also points out that in comparing the dates of vulval swelling given by Hill and Parkes with those observed by Hammond and Marshall [10], there was on the average a definite lag in the time of the onset of oestrus. Bissonnette [6] also noted that there was a delay in the onset of oestrus in two hooded ferrets. It would therefore seem that there is an inherent rhythm in the sexual life of the ferret, but that light is an auxiliary factor. On the other hand, Marshall has reported the case of a blind ferret which has never experienced oestrus; and it has also been found that in blinded toads (*Xenopus*) the ovary was under-developed [11].

In observations on the breeding of the field-mouse, Baker and Ransom [1] noted a remarkable general correlation between the hours of sunshine and reproduction in this species. In general, breeding occurred only in those months in which there was more than 100 hours of sunshine. This finding was supported by an experiment in which a reduction of the daily period of exposure to light from 15 to 9 hours almost prevented reproduction in the field-mouse [12].

Nutritional Factors and the Oestrous Cycle in Animals

Under-nutrition has been associated with sterility in many animals. It has been noted that the oestrous cycle in rats is not affected by mild nutritional deficiency, but it is lengthened when the diet is very poor; the cornified-cell stage is said not to be affected [13]. In the guinea-pig,

Papanicolaou and Stockard [14], and in the rat, Long and Evans [15] have found that under-feeding increases the length of the inter-ovulation period. Macomber [16] has also noted that a reduction of 30 per cent. in the total amount of food greatly prolonged the interval between periods of oestrus in the rat. Loeb [17] found that rats underfed on a normal ration failed to ovulate, and that follicles underwent degenerative changes.

Over-feeding likewise interferes with breeding efficiency. It is often difficult to get fat animals to breed, and Hammond has shown that the duration of oestrus and the length of the cycle are shortened in animals in fat condition. A considerable amount of lipochrome has been found in the ovaries of fat heifers [18]; and Hammond suggests that the decreased length of oestrus in fat animals may be caused by a blockage of the ovarian cells with lipoids.

Evans and Bishop [19] have found that fat-free diets interfered with ovulation, but no such interference was attributed to carbohydrate-free diets.

Guilbert and Goss [20] noted that in rats the oestrous cycle was normal with a protein-intake of 7·5–8 per cent. Lowering the protein-intake to 3·0–3·5 per cent. resulted in cessation of oestrus or in long, irregular cycles. It is not known to what extent an inadequate protein-intake, permitting oestrus (but not fertility), in some animals interferes with ovarian changes, for numerous *corpora lutea* that may have been newly formed, or may have been retained from the last oestrus, were found in the ovaries of such animals 70 days after the last occurrence of oestrus. The importance of the quality of the protein has been shown by Courrier and Raynaud [21], who found that the sexual cycle did not occur on a diet deficient in lysine.

Guilbert and Hart [22] found that a low phosphorus-intake caused cessation of the oestrous cycle in rats; in some cases irregular cycles occurred and the cycles were lengthened. A change to a diet adequate in phosphorus caused oestrus to start within a few days. The importance of the calcium-phosphorus ratio, as well as the actual amount of phosphorus in the diet, is shown by the fact that oestrus ceased on a diet low in phosphorus and high in calcium, but began again on transferring the animals to a diet containing an amount of phosphorus similar to that in the previous diet but with a low calcium-content. Lack of phosphorus in the diet is said to cause cessation of oestrus in cattle [23, 24]. In South Africa phosphorus-deficiency is associated with sterility in cattle [25, 26] and in Norway, Tuff [27] has noted that a naturally occurring deficiency of calcium and phosphorus in the food causes failure to ovulate. Contrary to these findings, Boyd [28] states that experiments still in progress (no details given) on the effect of phosphorus on reproduction show that there is no interference with the rhythm of the oestrous cycle in cattle.

The inability of rats to reproduce successfully when fed on a ration of milk alone is generally thought to be due to milk being low in certain substances necessary for reproduction. Ovulation was delayed and irregular in rats on a milk diet supplemented by copper and iron, but

the addition of manganese and iodine improved the ovulatory rhythm [29]. Skinner, Van Donk, and Steenbock [30] found that even on a milk-copper-iron diet supplemented with manganese, rats showed irregular and infrequent cycles. On the addition of sucrose to this diet normal oestrous cycles (4·3 days) occurred, and on the milk-copper-iron diet with sucrose, but without manganese, the oestrous cycles were regular but longer in duration (5·4 days). The deficiency of this diet with regard to oestrus therefore seems to be one of energy, although the maximum response was not elicited without the manganese. On the other hand Orent and McCollum [31] failed to find any interference with the periodicity of oestrus on a manganese-free basal diet, and on a milk-copper-iron diet. The author has noted that injection of oestrin in the form of urine from a pregnant cow into mice in which oestrus has ceased entirely, due to an exclusive milk diet, will induce oestrus again [unpublished results]. The failure of such mice to exhibit oestrus is therefore apparently due to non-production of oestrin.

There is almost complete cessation of oestrus in rats when the sodium-fluoride intake exceeds the threshold value of 25 mg. F per kg. body-weight [32]. Rats fattened on brain and cholesterol had longer dioestrous periods, but lecithin increased the duration of oestrus [33].

Vitamin-B deficiency is associated with atrophic changes in the male and female gonads. According to Evans and Bishop [19], this deficiency results in cessation of oestrus in rats. Marrian and Parkes [34] have found that the administration of anterior pituitary substance induced oestrus in the anoestrous condition caused in the rat by inanition or vitamin-B deficiency, and it has been found that oestrin has a similar effect in vitamin-B deficiency [35, 36].

Verzar [37] has shown that the intra-peritoneal injection of vitamin E into immature female rats caused hypertrophy of the uterus, but no such effect was observed in ovariectomized animals. Male rats reared on a diet free from vitamin E had a silky infantile coat similar to that of castrated rats; the addition of vitamin E to the diet, or the injection of anterior pituitary hormone into rats on that diet, caused the development of the bristly coat characteristic of the normal male. It is therefore suggested that vitamin E is necessary for the synthesis of anterior pituitary hormone [38]. Vogt-Moller and Bay [39, 40] have used extracts of wheat-germ oil against sterility in the cow with considerable success.

In view of the relationship known to exist between the anterior pituitary and the gonads, several workers have investigated the gonad-stimulating properties of the anterior pituitary of rats on diets deficient in various factors. Marrian and Parkes [34] transplanted the pituitaries from rats lacking vitamin B into immature anoestrous rats, and obtained a response similar to that with pituitaries of normal rats. Similarly, fairly high doses of fluorine do not seem to affect the gonad-stimulating potency of the anterior pituitary in rats [32]. On the other hand, Mason and Wolfe [41] obtained a 43 per cent. greater effect with the pituitaries of rats on a diet deficient in vitamin A than with controls on normal diets.

Influence of Climatic and Nutritional Factors on the Periodicity and Duration of Oestrus in the Cow

It was thought that if environmental factors affected in any way the periodicity and duration of oestrus, a correlation between one or more of these factors and the periodicity and duration of oestrus might be evident. Accordingly, meteorological data were recorded and analyses of the pasture on which the animals grazed were made. The meteorological data are summarized in Table 1. The rainfall data are available for the

TABLE 1. *Meteorological Data*

	1933											*1934*	
Months	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*
Rainfall (inches)	3·08	3·18	7·80	9·44	5·52	4·97	6·96	5·75	4·41	3·21	3·12	0·09	1·12
Temperature (°F.):													
maximum	..	..	..	..	..	..	75·8	78·4	78·1	79·4	83·4	90·6	90·6
minimum	..	..	..	..	..	..	56·2	56·2	58·9	68·6	58·9	57·0	61·9

whole of the experimental period, but temperature records only for the months August–February. Analyses of pasture are available for the period July–February; they are given also for the months of March and May, to show the full seasonal variation that takes place. There are no particulars for April, as the grass sample arrived in a mouldy condition and could not be analysed.

Climatic Factors

Rainfall.—It is unlikely that rainfall *per se* influences sexual function, but it might act indirectly through its effect on pasture. If this were so there would probably be a latent period before any effect would be obvious. May, with fully 9 inches of rain, was the wettest month of the year, and no increase in the duration of oestrus occurred until July, two months later, which would seem to be a long interval if rain really did exert any indirect influence. Also, there was actually a decrease in the month immediately following that of heavy rain. Moreover, the monthly rainfall decreases steadily from August to January, and the periodicity and duration of oestrus over the same period shows considerable variation. It may therefore be concluded that rainfall was not responsible for the variation noted in the periodicity and duration of oestrus.

Temperature.—In general, it can be said that climatic conditions in the tropics consist of a range from wet to dry weather, as opposed to the range from hot to cold weather in temperate climates. The stock-farm where the observations were carried out was not exposed to extreme temperatures (Table 1). Unfortunately records are available for only 7 months. They suffice, however, to show that the range of both maximum temperatures (from 75·8° in August to 90·6° in February) and minimum temperatures (56·2° in August to 61·9° in February) over the period are comparatively slight. In the wetter period of the year the temperatures would be somewhat lower. All workers are not agreed that temperature does affect reproduction, but it has been shown experimentally that only very low temperatures affect reproduction in the

mouse. The temperatures to which the experimental cattle were exposed were not extreme. Moreover, although the temperature increased steadily from August to February, both the periodicity and duration of oestrus over this period showed considerable variation. It is therefore

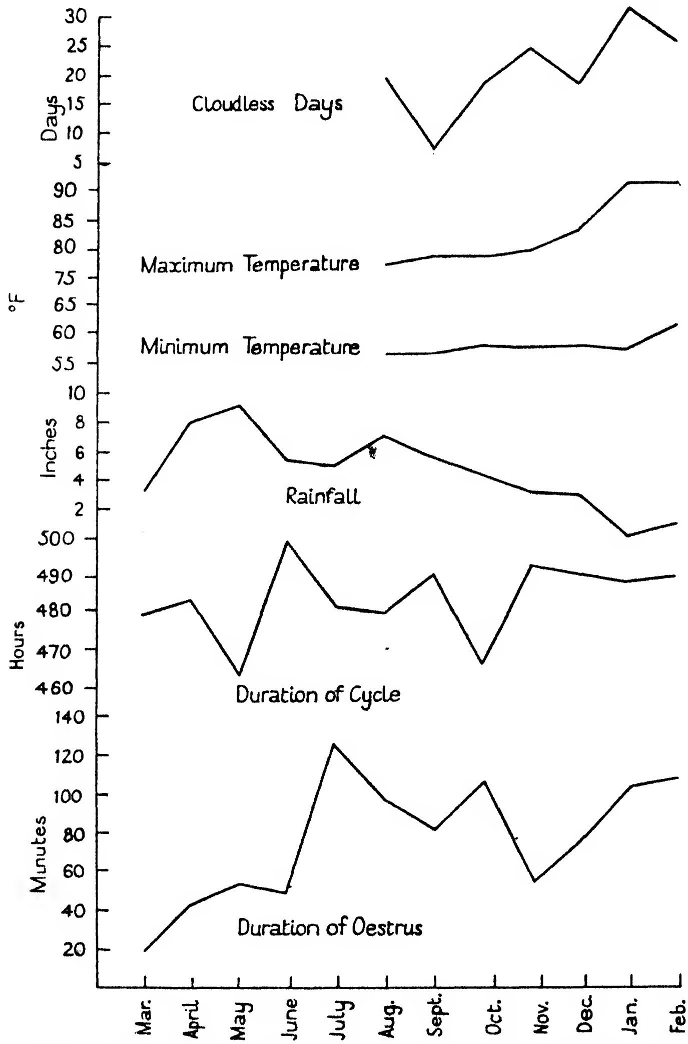

FIG. 1. Relationship between periodicity and duration of oestrus and rainfall, temperature, and cloudless days

concluded that in the present experiments temperature was not an important factor determining variation in the periodicity and duration of oestrus in cattle.

Light.—Circumstances unfortunately prevented the making of sunshine records, but a rough estimate of this factor was obtained from daily observations on the state of the weather, including the amount of cloud, and to some extent the data for rainfall and temperature (Fig. 1).

As the farm is situated almost on the equator, the length of the day varies little from season to season. Variation in the amount of sunshine must, therefore, be attributed to climatic conditions, and it may be assumed that, in general, there is less sunshine during the rainy season than in the dry season. An estimate of the state of the weather was made daily at 6 p.m., and the weather for the preceding 12 hours was also noted. For this purpose weather was regarded as: (*a*) 'cloudy', denoting a considerable amount of cloud, (*b*) 'variable sky', denoting a small amount of broken cloud, and (*c*) 'clear', when cloud was absent or at a minimum. The number of days per month with cloudy and clear weather was thus obtained (for this purpose 'variable sky' was regarded as 'clear' weather). It is admitted that this method is far from ideal, and can only give a very rough estimate of the amount of sunshine but, in the absence of more accurate data, it must for the present suffice. It will be seen from Fig. 1 that on the whole there is some similarity between the amount of sunshine, as represented by the number of days per month without cloud, and the variation in the duration of oestrus. In view of what is known of the effect of light upon reproductive functions, and bearing in mind the limitations of this method, it is apparent that the influence of light on sexual function in the cow is worthy of further investigation.

Food.—Analyses of the pasture, which formed the sole food of the animals during the experiment, is given in Table 2. It is evident that the pasture is of poor nutritive value. The contents of phosphorus, ash, chlorine, and protein, are particularly low. It is probable that the sodium-content is also low. The relationship between rainfall and pasture constituents is shown in Fig. 2.

The effect of rainfall is, on the whole, clearly reflected in the pasture constituents, an increase in the monthly rainfall being associated, in general, with an increase in the percentage of most of the constituents, and vice versa, with the exception of the month of October when, with a decrease in rainfall, an increase in the crude protein, silica-free ash, CaO and P_2O_5 occurs. The protein and silica-free ash follow each other closely, but the protein-content of the pasture increases more promptly than does the silica-free ash in response to the increased rainfall in February. Actually the P_2O_5-content parallels the protein-content much more closely than does the silica-free ash, though the variation in the P_2O_5-content is comparatively slight. Variation in the chlorine-content is likewise slight; it rises steadily till December and then falls till March, the highest value occurring in May. The CaO-content also rises till the month of October; it falls slightly in November, rises in January, falls in February, and rises again in March.

There does not appear to be any relationship between seasonal variation in the pasture constituents and variation in the periodicity and duration of oestrus. A decrease in the duration of oestrus in August–September and in October–November is accompanied by a decrease in the crude protein, P_2O_5, and silica-free ash, but while these constituents continue to fall from November–January, the duration of oestrus increases. An increase in the duration of oestrus in September–October and in January–February is associated with an increase in the crude

protein and P_2O_5 over the same period, but an increase in these constituents is accompanied by a decrease in the duration of oestrus in July–August. A decrease in the length of the cycle in November–January

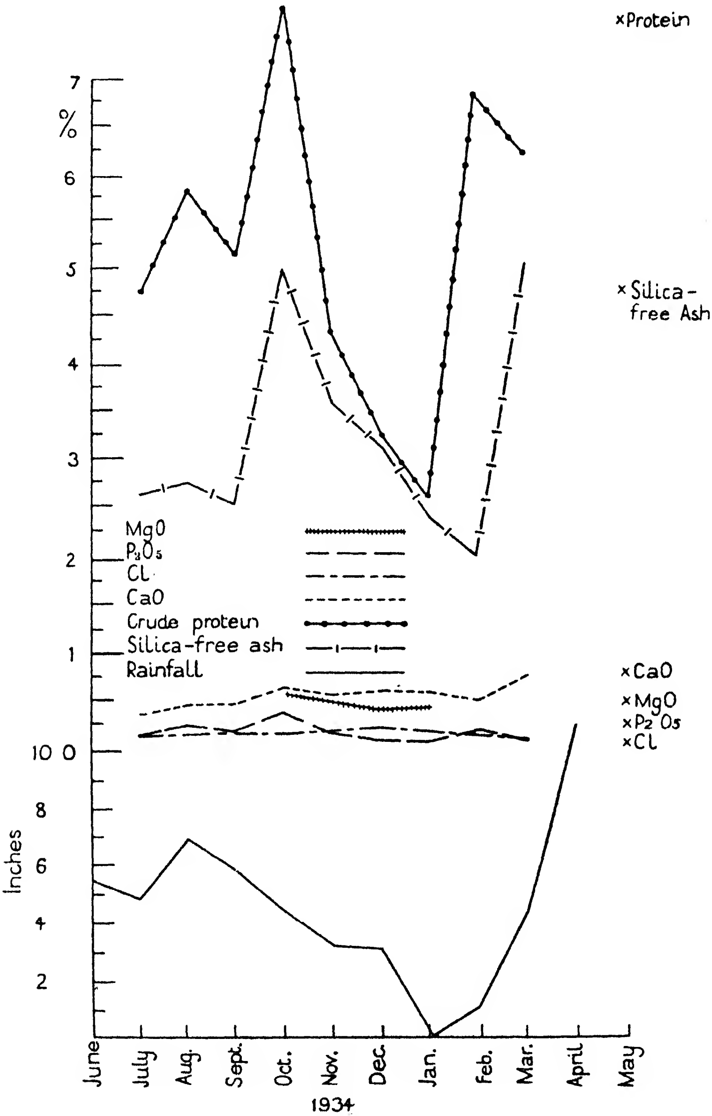

FIG. 2. Relationship between rainfall and pasture constituents

is associated with a decrease in the crude protein, silica-free ash, and P_2O_5, but an increase in the former in August to September is accompanied by a decrease in the crude protein, silica-free ash, and P_2O_5. The variation in the contents of chlorine and calcium does not correspond with variation in the periodicity or duration of oestrus. Such variation

as there is in these substances is slight, and there is no evidence that they are of great importance to reproductive functions.

Since in the method used for sampling the grass a certain amount of old grass was probably included, it is doubtful if the analyses fully represent the seasonal changes in the pasture constituents. Moreover, although no relationship is evident between the pasture constituents and the periodicity and duration of oestrus, it must be remembered that the percentages of pasture constituents shown in Table 2 do not necessarily

TABLE 2. *Analyses of Pasture Herbage*

Date of cutting	*Crude protein*	*Ether extract*	*Crude fibre*	*N-free extract*	*Silica-free ash*	*CaO*	*P_2O_5*	*Cl*	*MgO*
1933									
July 28	4·75	1·70	34·06	50·03	2·67	0·39	0·17	0·15	..
August 31	5·84	1·28	33·94	48·99	2·78	0·49	0·27	0·16	..
September 30	5·15	1·82	32·60	50·83	2·54	0·50	0·21	0·17	..
October 31	7·78	1·36	29·77	51·72	5·02	0·66	0·40	0·17	0·52
November 30	4·36	1·46	31·97	52·83	3·60	0·60	0·19	0·20	0·52
1934									
January 7	3·29	1·40	32·90	52·40	3·15	0·63	0·11	0·21	0·44
January 31	2·60	1·46	31·07	55·22	2·40	0·61	0·10	0·13	0·46
February 28	6·80	1·25	33·08	48·25	2·00	0·52	0·19	0·12	..
March 31	6·20	1·74	32·50	47·60	5·09	0·79	0·13	0·13	..
April 30	..	..	..	..	..	..	..	..	..
May 31	7·57	1·77	32·77	48·66	4·76	0·53	0·37	0·27	0·55

indicate the amounts of them consumed by the animals. No check was made on the food-consumption, and it is therefore possible that more pasture was eaten at certain times of the year than at others. It is therefore concluded that this method of correlating seasonal variation in the periodicity and duration of oestrus with seasonal variation in the pasture constituents is not one that will lead to useful results.

On the other hand, in view of what is known of the effect of shortage of protein and P_2O_5 in the diet of animals on the oestrous cycle, it is possible that the relatively small amounts of protein and phosphorus in the pasture are related to the brief duration of oestrus in the experimental animals.

Discussion

It has been shown that Zebu cattle exhibit a very short oestrous period compared with British cattle; but as the animals were living under conditions totally different from those of cattle in Britain, and on a diet poor in protein and phosphorus, the question of the relative effect of breed and nutrition on the oestrous cycle must for the present remain open.

It does, however, seem to be significant that the duration of oestrus is long at that time of the year in Kenya when there is most sunshine, namely, the dry season. The fact that the oestrous period is also long in July and October may or may not be related to the amount of sunshine. The possible significance of the relationship between the duration of oestrus and sunshine is enhanced by the facts that, (*a*) in Britain oestrus is longer in cattle during the summer months than in the winter months, and (*b*) light has a stimulating effect on reproductive function

in birds, mice, and ferrets. If light as a stimulus to reproductive function is to be regarded as a factor of universal importance, it is generally considered probable that it is the change in the light ration and not the actual amount which is the decisive factor, for most breeds of sheep, for example, commence their mating season when the hours of daylight are decreasing in the autumn, and mating stops with increasing daylight in the early spring.

Variation in the duration of oestrus can probably be related directly to variation in the production of oestrone, the hormone responsible for the oestrous phenomena in animals, and this in turn to variation in the gonadotropic activity of the anterior pituitary. It has been shown that hypophysectomy in the ferret prevents the response to light treatment which is obtained in the normal animal [8]. It is therefore possible that light is capable of stimulating the anterior pituitary in cattle, possibly through the eye.

Summary

1. Present knowledge on possible relationships between rainfall, temperature, light, food, and reproduction is reviewed.

2. The possible influence of climatic and nutritional factors on the periodicity and duration of oestrus in the cow was investigated. No correlation was found for rainfall or temperature, but some indications were found of a possible correlation between sunshine and variation in the duration of oestrus.

3. Analyses of the pasture (which formed the sole food of the experimental animals), cut at monthly intervals, were made for the period July 1933 to May 1934. No relationship was found between seasonal changes in pasture constituents and the periodicity and duration of oestrus. This line of investigation is unlikely to lead to useful results.

Acknowledgements

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THE ROOT-SYSTEM OF THE SUGAR-CANE

II. SOME TYPICAL ROOT-SYSTEMS

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WITH PLATE 13

IN the first paper of this series (1935, **3**, 351) a description was given of one typical sugar-cane root-system and of the various classes of roots composing it. Although these classes of roots are represented in most sugar-cane varieties, their relative proportions vary greatly, giving rise to considerable differences in the mature root-systems. The root-systems of most of the economic varieties in Mauritius have been investigated in considerable detail, and it is proposed to describe here the most important varietal types.

The First-nobilized Glagah Type

First-nobilized Glagah canes are of no direct economic value, being the first generation from the cross of the wild Java forms of *Saccharum spontaneum* with the noble cane *Saccharum officinarum*, but they are of great value for breeding purposes. Attempts are, however, being made in Mauritius to produce third- and fourth-nobilized Glagah canes for commercial cultivation. Since the nature of the root-system of the parent types used for breeding will presumably have a marked effect on the nature of the root-system of the seedlings produced, the root-system of the parent type was studied in detail.

The surface-soil of the field where this root-system was examined was only 6 in. deep, the soil below consisting of a friable, reddish brown clay. The root-system in the first 6 in.-layer of soil is very extensive, spreading uniformly in all directions. Roots in this layer generally originated at a depth of more than 6 in. at the stool, but came nearer to the surface as they passed away from the stool, their final terminations being only 3–4 in., or even less, below the surface of the soil. Towards their terminations, the roots branched profusely, the branch-systems generally consisting of very thin and delicate rootlets. Roots 10 ft. long were found in this layer, and the number and length of roots appeared to be correlated with the vigour of the aerial portion of the stool. The roots in the surface-layer were cylindrical and rather thin, being also hard, wiry, and brownish black. They showed no compression in passing through the soil, but older roots were often ribbed, as in the shoots of some switch plants. This was shown to be due to the collapse of cortical cells at some points, leading to the depressions in the hypodermal layers. The superficial absorbing roots were confined to the first 6 in. or so of soil, the roots in the soil immediately below being buttress-roots. These buttress-roots were deep yellow to orange at the time of examination, indicating a comparatively recent origin. They did not branch to any great extent, and showed marked distortions. Most of the buttress-roots passed outwards

and downwards from the stool, generally terminating at a depth of 3–4 ft. Some passed more or less vertically downwards. In the deeper layers the roots did not pass outwards to any marked degree, but generally passed more or less vertically downwards. These deep roots, like those of the superficial system, are cylindrical, and in this variety associate to form well-defined rope-systems. The rope-systems passed down to depths of 7–9 ft. under the particular conditions of growth.

The root-system of this type of sugar-cane is thus in the main a very satisfactory one in regard to number and distribution of roots in the various soil layers. The reconstructed root-system of a comparatively small stool of a first-nobilized Glagah seedling is shown in Fig. 1, Plate 13. Many of the roots were, however, followed to much greater depths than 6 ft., which is the depth of the frame in this figure.

The POJ. 2878 × Uba Marot Seedling Type

One of the most striking types of seedling produced by the Sugar-cane Research Station is that obtained by crossing the Java cane POJ. 2878 with the Mauritius cane, Uba Marot. POJ. 2878 contains one-eighth of the wild blood of *Saccharum spontaneum*. The origin of Uba Marot is unknown, but it is certainly different from Uba, and almost certainly contains wild blood, its chromosome number being 112 or 113, most probably 113 (Bremer, 1934). The progeny of this cross have remarkable vigour, particularly in the early stages of growth. Several such seedlings have been produced to date, and some of them have satisfactorily survived field-trials for yields of cane and sugar per acre. One stool was reconstructed in a specially made frame, and a few other stools were examined in less detail. The stools examined were virgin, or plant-stools of 18 months, and bore on the average 35 canes. The root-system was one of the most extensive of all the varieties that have been examined. The surface-spread of the root-system, though appreciable, has been excelled by certain other varieties. Branching of the surface-roots was not prolific, but the number of roots in the surface-soil was very high. The typical superficial roots were not in this variety confined to the first foot or so of soil, as is generally the case. Roots in the second foot were nearly as numerous as those in the first foot. Down to a depth of 2–3 ft. the roots passed outwards more or less horizontally from the stool, contrasting markedly with the noble canes, in which roots passing outwards horizontally are seldom found below a depth of 1 ft. In addition, the noble canes seldom have many roots at depths of 4–5 ft., but this system showed very active root-development at this depth, and rope-systems passed down to far greater depths. Buttress-root development had been very vigorous, the buttress-roots being somewhat thinner and darker than in most noble canes. Below 4–5 ft., most of the roots were associated as rope-systems passing down vertically. Several rope-systems were followed to a depth of 15 ft., and at this depth there was a considerable number still descending. The number and extent of the roots from the surface-soil down to these depths were very great.

Less detailed examination of other seedlings of this cross showed that they all had very satisfactory root-systems. It is probable that selected

seedlings of this type will play an important part, particularly on lands infested with *Phytalus Smithi*, Arrow, a white-grub pest in Mauritius. The root-system in the first 6 ft. of soil is shown in Fig. 2, Plate 13.

The Uba Type

Among the Uba type are included the ordinary Uba cane together with various seedlings of Uba that have inherited the general characteristics of the Uba type of root-system.

The root-system of the ordinary Uba is the most extensive of all the root-systems examined, not excepting that of the POJ. 2878 × Uba Marot seedlings.

The Uba type of root-system was too extensive to be profitably investigated by the 'block' method, and more information was required than could be obtained from the direct-examination method. All these root-systems were therefore investigated by the progressive-section method (Pt. I, this *J.*, 1935, p. 354), and the description of the root-system will therefore be given in accordance with the method used. The description which follows refers in the main to ordinary Uba. The superficial system was very extensive, by far the most extensive of all the varieties examined, not only as regards number of surface-roots but also as regards length and degree of branching. Six feet away from the stool there was a large number of roots, some of which were found even at this distance from the stool at a depth of 3½–4 ft. The longest superficial roots were, however, 12 ft. or more in length, branching profusely for 2–3 ft. from their terminations. There were few roots of this length. At 4 ft. from the stool there were not many more roots in the first 2 ft. of soil than at 6 ft., showing that relatively few roots terminate between 4 and 6 ft. The number of roots below 2 ft. is, however, markedly greater, passing down to depths of 4–5 ft., some being associated as rope-systems even at this distance from the stool and passing down to 7 ft. In one of these rope-systems there were twenty roots of various orders. The deeper roots were thicker and less branched than the superficial roots.

At 2 ft. away from the stool the number of roots was outstanding; the number in the first 2 ft. of soil was materially greater than at 4 ft. from the stool, showing that many roots only passed outwards to 2–4 ft. It was found that several of the roots actually ended in this region, whereas others merely passed outwards to this distance and then turned downwards. At 2 ft. from the stool numerous rope-systems passing down to depths of 8–10 ft. were encountered.

The final section at the edge of the stools showed very vigorous root-growth: there were some new white roots varying from a few inches to a foot in length emerging from the stool. Branching of the surface-roots was not nearly so prolific near the stool as at considerable distances away from it. Buttress-roots were extremely well developed, but were somewhat thinner and darker than usual. It is the rope-systems, however, which show their maximum development in this variety. Below a depth of 6 ft. very few roots were found that were not associated as rope-systems. Rope-systems were followed down to a depth of 18 ft.; at this

point there was a bed of rock, which made it impossible to continue the trench. The rope-systems turned inwards, following the face of the rock, so that their subsequent course could not be determined. There is little doubt, however, that the rope-systems of Uba pass down to a

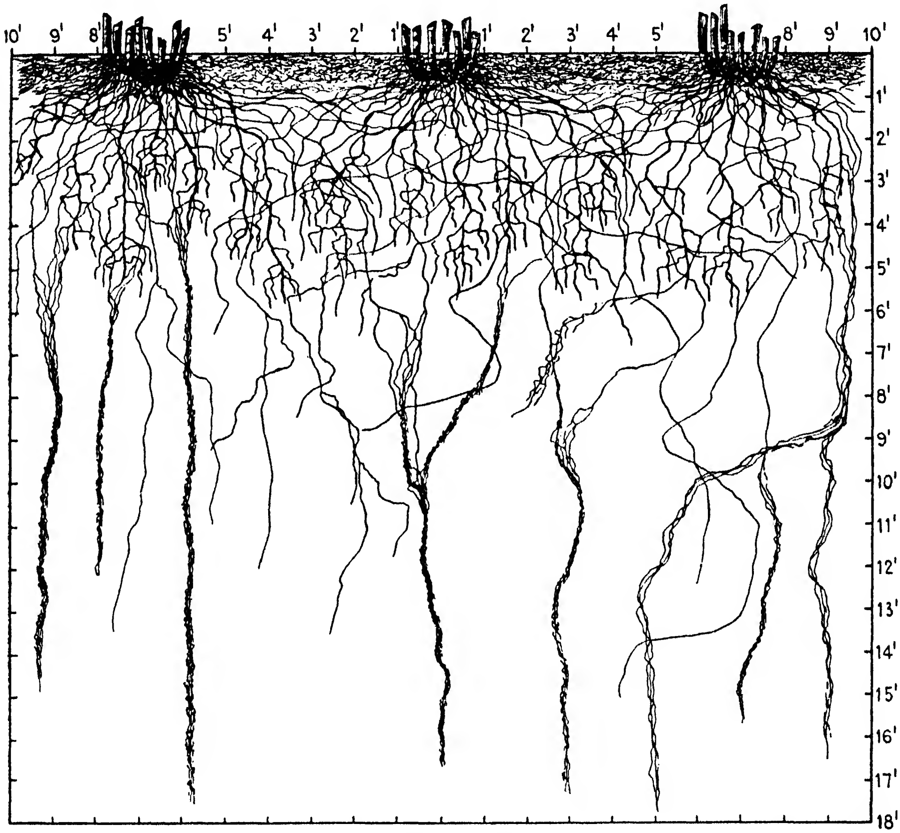

FIG. 3. Uba

depth of at least 20 ft. under these particular conditions of growth. So far as the author is aware, this is the greatest depth to which the roots of sugar-cane have been followed.

The root-systems of Uba Seedling, White Uba, Uba Seedling Brown Sport, &c., follow the same general distribution as that described above for ordinary Uba, but they are much less extensive than those of the parent type. In respect of number of roots, spread, degree of branching, &c., the Uba seedlings fall far short of ordinary Uba, though compared with some of the noble canes their root-system is markedly superior. The root-system of ordinary Uba is shown in section in Fig. 3.

Before leaving the Uba type of root-system, mention must be made of the variety Uba Marot. This cane was found in 1923 by Mr. L. Marot in a field at Gros Caillaux, Mauritius, and has proved to be of great value for breeding purposes. Its root-system is very extensive, but

different in several respects from the Uba type. The superficial roots are much thicker, more deeply seated, and less branched.

Roots belonging to the surface-system and passing out laterally are numerous to a depth of 2 ft. Among the preponderating thick surface-roots are shorter, thinner, and more branched roots, but the latter are few in this variety. Although certain of the surface-roots attain a length of 7–8 ft., the system has not nearly so large a spread as in Uba. Buttress-roots and rope-systems are numerous, but root-development below 5 ft.

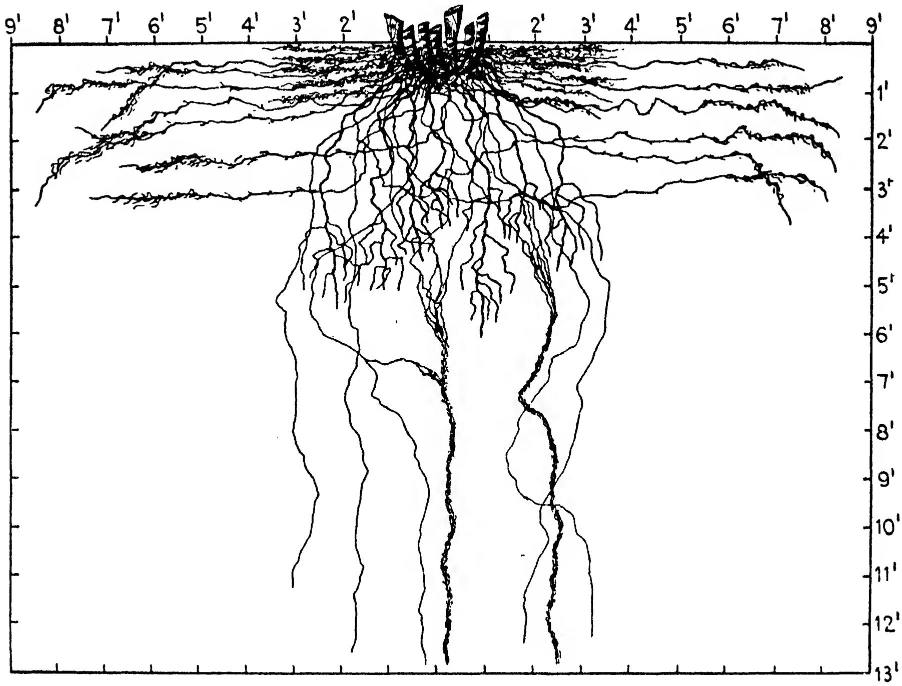

FIG. 4. Uba Marot

is not nearly so extensive as in Uba. The system as a whole shows several affinities to those of seedlings of the POJ. 2878 × Uba Marot cross, and there is little doubt that Uba Marot has exerted a much stronger influence on the root-system of these seedlings than has the female parent, POJ. 2878. The root-system of Uba Marot is shown in Fig. 4.

The POJ Varieties

Although for convenience the varieties produced by the Proefstation Ost Java are grouped here under one heading, they show considerably more variation than do any of the other root-types considered in this paper, perhaps in part due to their origin from Chunnee or Glagah types, respectively. The POJ canes whose root-systems have been examined in detail include the following numbers: [POJ] 36, 213, 2940, 2878, 2727, 2747, 2364, and 161.

The root-system of POJ. 36 is comparatively superficial, the vast majority of the roots being present in the first foot of soil. The surface-roots show prolific branching, but do not attain great lengths. The buttress-system is adequately developed, but there are comparatively few rope-systems. POJ. 2747 and POJ. 2940 may be dealt with briefly here, since under Mauritius conditions both these varieties have a very meagre and poorly developed root-system.

In POJ. 2940 the roots are few and very superficial. Buttress-roots were present, and one rope-system was seen. The poor root-growth is

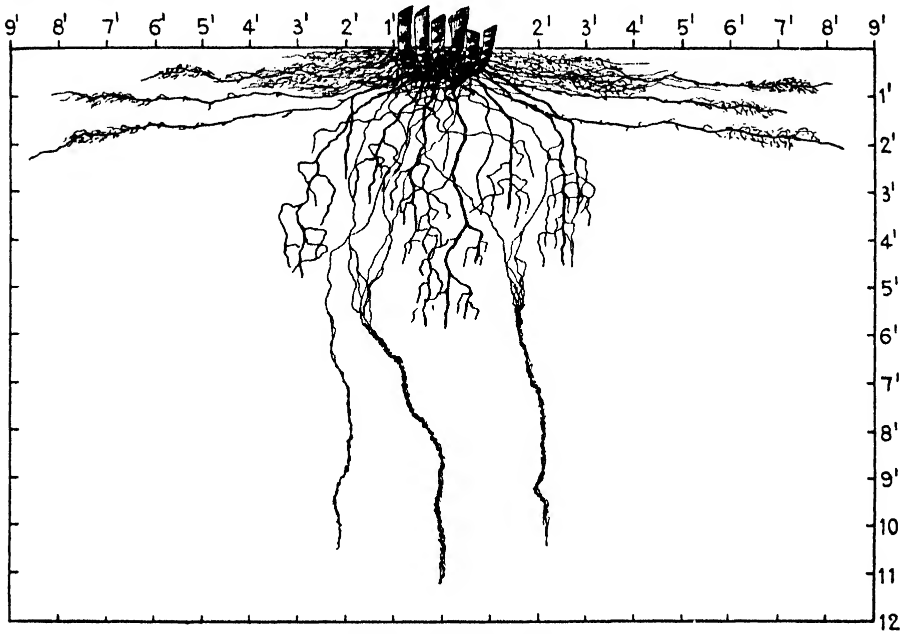

FIG. 5. POJ. 2727

correlated with comparatively poor top-growth consisting of large canes but very few in number. POJ. 2747 has a more deeply seated root-system than has POJ. 2940, but the roots are very short and few. The variety POJ. 213 has a very satisfactory root-system. It appears to be better balanced from the point of view of absorbing and anchoring than most of the noble canes. The superficial system is similar to that of POJ. 36, showing profuse branching, the roots being in the main comparatively short (up to 4 ft. long). In addition there are several longer surface-roots passing outwards at a depth of 6–12 in. and branching towards their terminations. The buttress-system is extremely well developed, the buttress-roots being much branched, but as in all cases of branching of the buttress-roots, the laterals are stout and not fibrous. There was a good average development of rope-systems, some passing down to 12–13 ft. Long, deeply seated rhizomes were common in this variety.

POJ. 2878 and POJ. 2727 have somewhat similar root-systems. The

superficial system is fairly extensive though not so much branched as in POJ. 36. POJ. 2878 is characterized by the thinness of the surface-roots, even the long main surface-roots being comparatively thin. Branching of the surface-roots is more marked in POJ. 2727, and some of the deeper surface-roots were longer and thicker than in POJ. 2878, some attaining a length of 8–9 ft. As the stools mature, both varieties have a tendency to form a large number of short superficial roots at or near the soil surface.

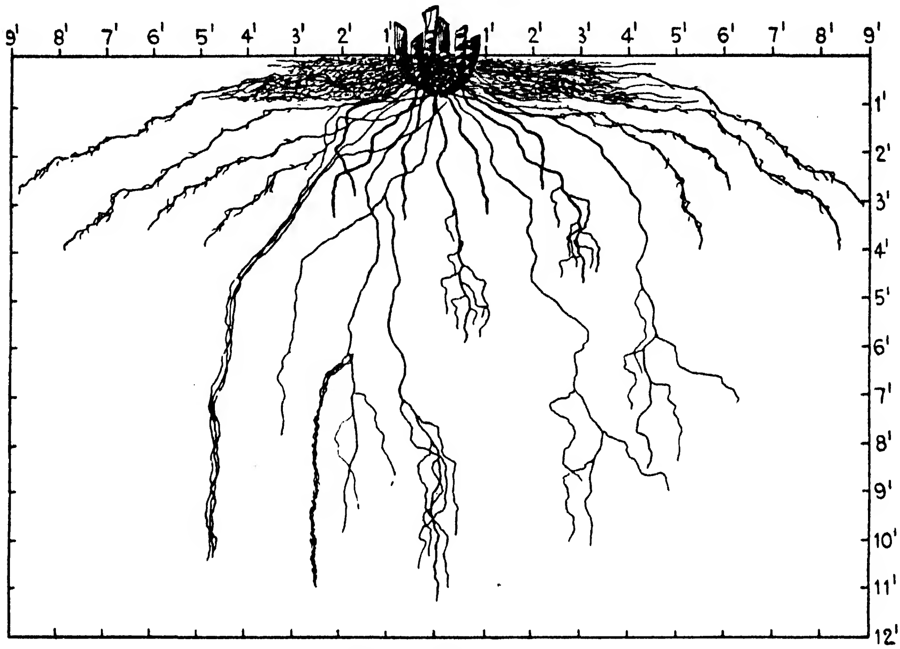

FIG. 6. POJ. 2364

The buttress-roots in POJ. 2878 were generally found descending to a depth of 4–5 ft., but immediately beneath the stool the buttress-roots were better developed and often reached a depth of 7 ft. These roots were normal in type. There were very few rope-systems.

In POJ. 2727 there was a stronger development of buttress-roots than in POJ. 2878; branching was also more prolific, and the buttress-roots showed to an extremely marked degree the distortions characteristic of these roots. Some rope-systems were also present, which at a depth of 8–9 ft. were still descending.

Considered as a whole, the root-system of POJ. 2878 though vigorous, is not outstandingly so. Jensen states that this variety has a tendency to produce roots in the upper soil-layers during the early part of the growth-period, the deeper roots developing later, so that in the mature plants they were almost as long as those of other varieties. There is little doubt, however, that POJ. 2727 (Fig. 5) has a superior root-system to POJ. 2878, though in distribution the root-systems of the two varieties show close similarity.

POJ. 2364 is a cane with a considerable amount of wild blood. It is unsuitable for commercial purposes, but invaluable for breeding, being the female parent of the famous POJ. 2878 and other good Java canes. As in most of the POJ canes the first 6 in. of soil contain many thin, profusely branching roots, but in addition there are other superficial roots which are thicker and branch only at considerable distances from the stool. Some of these longer superficial roots attain a length of 10 ft. They generally follow a horizontal course at a depth of 4–9 in., and some turn downwards to 1½–2 ft. towards their terminations. Groups of thick superficial roots often followed canals formed by insects to considerable depths (Fig. 6). These groups must not be confused with rope-systems, where the association is much more intimate.

The typical 'superficial' system is, in this variety, much more deeply seated than is normally the case, and appears to take the place of the buttress-system to a large degree; the normal buttress-roots are very few. Rope-systems, on the other hand, are quite well developed, and pass down to considerable depths. The system as a whole is thus very vigorous and deeply seated, making it probable that seedlings of this variety will not suffer from meagre root-development.

The variety POJ. 161 has an average root-system. The superficial roots extended to a distance of 6½–7½ ft. At 6 ft. from the stool there were no roots below 14 in. Branching was vigorous between 3 and 5 ft. from the stool. Buttress-roots were not numerous, but thick surface-roots similar to those described for POJ. 2364 passed down galleries formed by insects. Rope-systems were moderately well developed and were still descending at 7–8 ft.

Another (East Indian) variety which has a good root-system is Selangor Seedling; its surface-system is very similar to that of POJ. 2364, having long, thick surface-roots in addition to short thinner ones. Unlike POJ. 2364, however, it has a well-developed buttress-system, the buttress-roots being extremely thick, one of 1 cm. diameter having been found. The buttress-system is very similar to that of POJ. 2727, and, as in the latter variety, and in POJ. 2878, there is only a restricted development of rope-systems. Some of the other (East Indian) varieties studied, such as Penang, SW. 499, had very mediocre root-systems of the noble-cane type.

The Tanna Type

There are several forms of Tanna canes grown in Mauritius, the most widely cultivated being White Tanna. Among the Tanna canes whose root-systems have been investigated are White Tanna, Black Tanna, Striped Tanna, Tanna St. Aubin, and White Tanna Mon Desert. The variations in the root-systems within this class are comparatively insignificant. The root-system is peculiar in that roots are very numerous to a depth of about 2 ft.; but there is a well-marked line of demarcation at this point, very few roots indeed being found below 2 ft. (Fig. 7). The Tanna varieties differ in the number of roots in the first 2 ft., White Tanna having the most roots in this zone. Profuse branching near the stool is not at all common in this variety, only the younger, shorter roots

having this character. In general, the superficial roots are fairly thick and unbranched near the stool, but branch profusely towards their terminations. Several of the surface-roots took a downward course from their point of connexion in the stool, but at a depth of about 2 ft. changed their course and became horizontal, passing along at this depth either well down the interline or sometimes underneath adjacent stools and into the adjoining interline. Buttress-roots are numerous, but they also travel outwards, so that comparatively few reach a depth of 3–4 ft. White

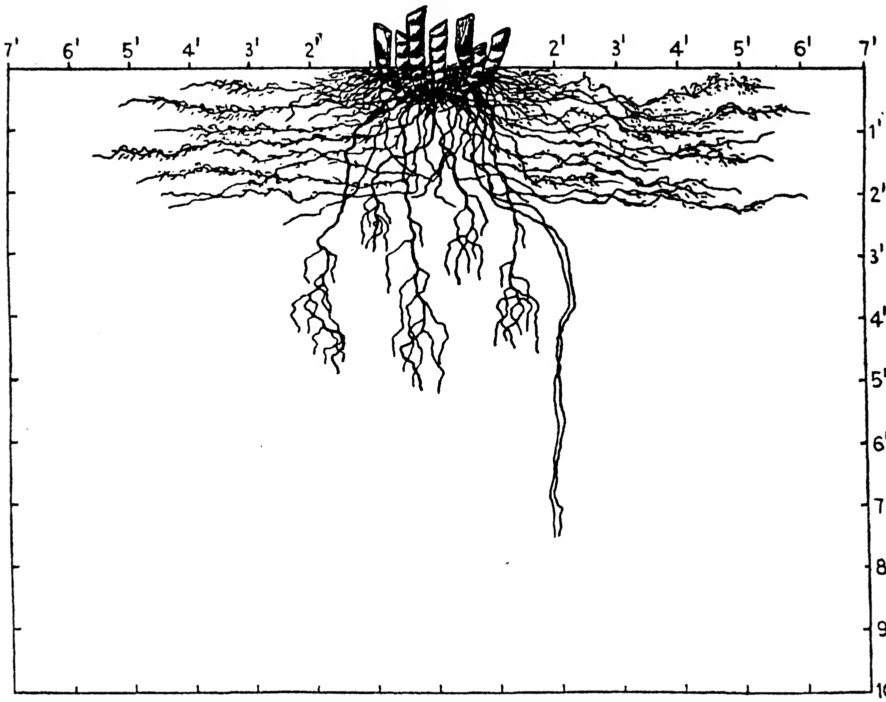

FIG. 7. White Tanna

Tanna, Black Tanna, and Striped Tanna conform accurately to this type, but some of the other Tanna varieties show slight differences. In Tanna St. Aubin the demarcation of roots between those in the first 2–2½ ft. and those below this depth is not so marked, and root-development in the surface-soil is not nearly so vigorous. There is, however, a slightly larger number of deeper roots, some buttress-roots attaining a depth of 5–6 ft. The best development of deeper roots occurs in White Tanna Mon Desert. In this variety, as in Tanna St. Aubin, the demarcation between the superficial and deeper roots is not so marked. The deep roots of this variety also are exclusively buttress-roots. Buttress-roots and their branches are fairly numerous to a depth of 5–6 ft. No rope-systems were encountered in the Tanna varieties. The system is an extremely good superficial system, but lacking in adequate formation of deep roots. This explains why most of the Tanna varieties are not suited to dry localities but perform remarkably well in the wet localities.

The Barbados Type

The typical example of the Barbados type of root-system is that of BH. 10(12) (Fig. 8). There are three other important West Indian varieties having a root-system that is sufficiently similar to be classified under the same heading, viz. SC. 12(4), D. 1135, and RP. 8. It is well known that in certain plants there is a correlation between the orientation of the leaves and the distribution of roots, the water dripping from the

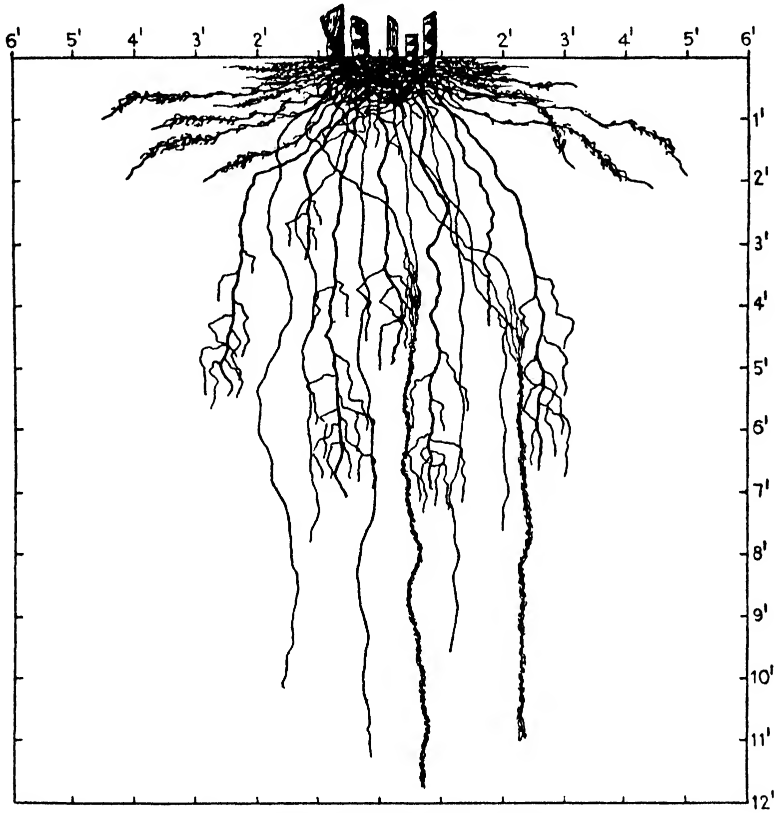

FIG. 8. Barbados BH. 10(12)

leaves being directed towards the absorbing region of the roots. Typical extremes are beet, with leaves orientated to direct water towards the tap-root, and the common nasturtium (*Tropeolum majus*), with leaves orientated to direct water towards the spreading fibrous root-system. The orientation of the leaves in the canes, here classified as the Barbados type, is characteristically different from what obtains in most of the other cultivated canes in Mauritius. The leaves stand more or less upright, and in accordance with this orientation the root-system is located much nearer the stool than is usually the case. In BH. 10(12) the extent of the superficial system is comparatively restricted; the number of roots is also smaller than usual and more sparsely branched. Superficial roots are, in the main, up to 2 ft. long, though a few reached 4–5 ft. Buttress-

roots were very numerous and descended more or less downwards beneath the stool to a depth of 6–7 ft. Rope-systems were fairly numerous but not of a very elaborate type, and descended to a depth of about 10 ft. Most of the roots of this variety had an oldish and very dark appearance, and there were very few new roots, either main roots or branches, with the exception of a few root-primordia just below the soil-surface that had germinated to give rise to young white roots. The distribution of roots is thus very satisfactory, root-development having taken place to considerable depths. The system, when examined, however, appeared to lack vigour and vitality, although this might have been an abnormal condition due to some unknown local factor.

The root-system of SC. 12(4) is similar in essentials to that of BH. 10(12). It shows a more vigorous development of superficial roots, though in this case also the spread is small, the system being situated close to the stool. Buttress-roots are very well developed, descending to 6–7 ft. The development of rope-systems was not so pronounced as in BH. 10(12), only a few rudimentary rope-systems being seen. There is thus less extensive root-growth in the deeper soil-layers in SC. 12(4), as compared with BH. 10(12). In D. 1135 also the superficial system consists of relatively short roots with a few longer roots at a greater depth. Buttress-roots were well developed but passed more or less vertically downwards and did not spread outwards to any marked degree. They attained depths of 6 ft. Rope-systems were few and very rudimentary, having only 2 to 3 roots in association. Branching of all the root-types is very sparse. The system is thus very similar to that of BH. 10(12) and SC. 12(4), but more restricted in its growth.

RP. 8 also has a very similar type of root-system; the surface-system is rather deeply seated and located in close proximity to the stool. Buttress-root development is stronger than in most varieties. The root-systems included here under the heading of the Barbados type are thus similar, in that they show a reduced superficial system situated very near the stool, accompanied by vigorous formation of deeper roots located for the most part directly beneath the stool.

Mauritius Noble Seedling Types

Several of the older noble canes bred in Mauritius that have become of some commercial value have been examined. These include the 1916 seedlings M. 20/16, M. 23/16, M. 27/16, and M. 29/16; also M. 13/18, M. 7/23, M. 14/26, M. 109/26, and M. 55/1182. There is nothing out of the ordinary in these root-systems, all the varieties having a root-system of the typical noble-cane type but with variations according to the variety. The noble-cane type exemplified by these varieties is a comparatively shallow system. Sixty per cent. or more of the roots is found in the first foot of soil, and the number of roots reaching below 4 ft. is negligible. The superficial system is generally very extensive, the roots being 6–7 ft. long and branching profusely towards their terminations. Buttress-roots are common in all these varieties, but generally they are not outstanding in their development. There are considerable differences in

the mean diameter of the roots in these noble canes, the magnitude of the differences involved being seen from the following table:

	Mean diameter of roots	*Standard error of mean*
M. 13/18 . . .	1·91 mm.	0·014
M. 14/26 . . .	1·28 ,,	0·003
M. 7/23 . . .	1·79 ,,	0·007

M. 109/26 was characterized by vigorous formation of buttress-roots, even very young shoots with no unfolded leaves bearing 8 to 10 thick

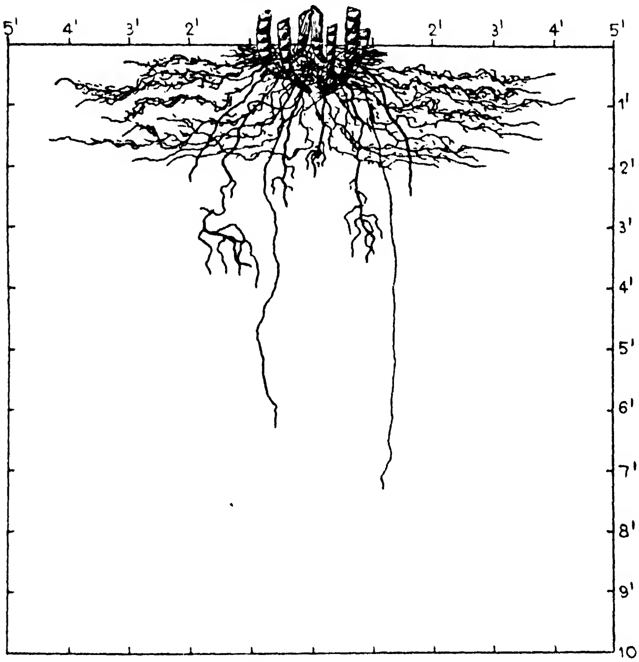

FIG. 9. M. 23/16

buttress-roots. Among these noble-cane types, the best root-systems were found in M. 109/26, M. 23/16, and M. 27/16. Examples of this type of root-system are shown in Figs. 9 and 10.

Miscellaneous Noble-cane Types

Among the other noble canes grown commercially in Mauritius whose root-systems have been examined in detail are RP. 6, ordinary and striped, DK. 74, DK. 74/70, and among the old cultivated varieties that have gone out of cultivation because of susceptibility to diseases, Sealy's Seedling, Rose Bambou, and Port Mackay. These were examined mainly to find varieties with suitable root-systems for breeding-work. All these varieties have root-systems of the noble-cane type, Port Mackay being characterized by very thick roots. The root-system of RP. 6 was somewhat below average in its development.

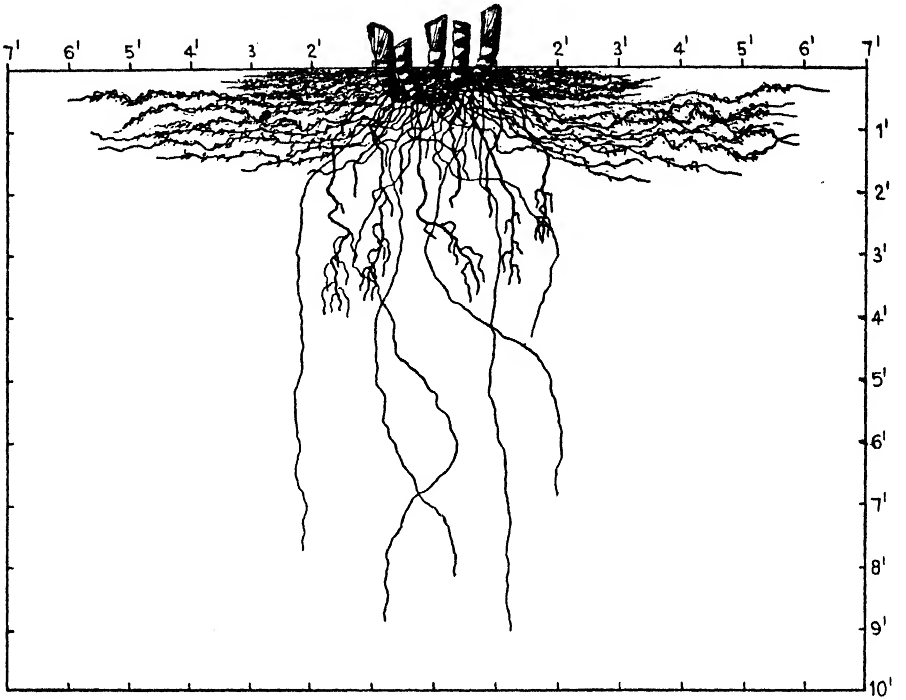

FIG. 10. M. 27/16

Summary

The root-systems of several varieties of sugar-cane have been examined in detail with a view to selecting canes of satisfactory root-growth for breeding and for cultivating under various environmental conditions prevailing in Mauritius. The nature of the root-systems enables one to indicate what canes are likely to do well in dry localities, in very wet localities, and in localities heavily infested with the root-eating grubs of *Phytalus Smithi*. It is also possible to indicate the degree of cyclone-resistance from the nature of the root-system. Data on the root-systems also provide a basis on which to evolve programmes for fertilizer application and various cultural practices. The data included in this paper represent a bare statement of the essential features of sugar-cane root-systems. In a later paper further information on various aspects of root-growth in sugar-cane, and the practical application of the results, will be considered.

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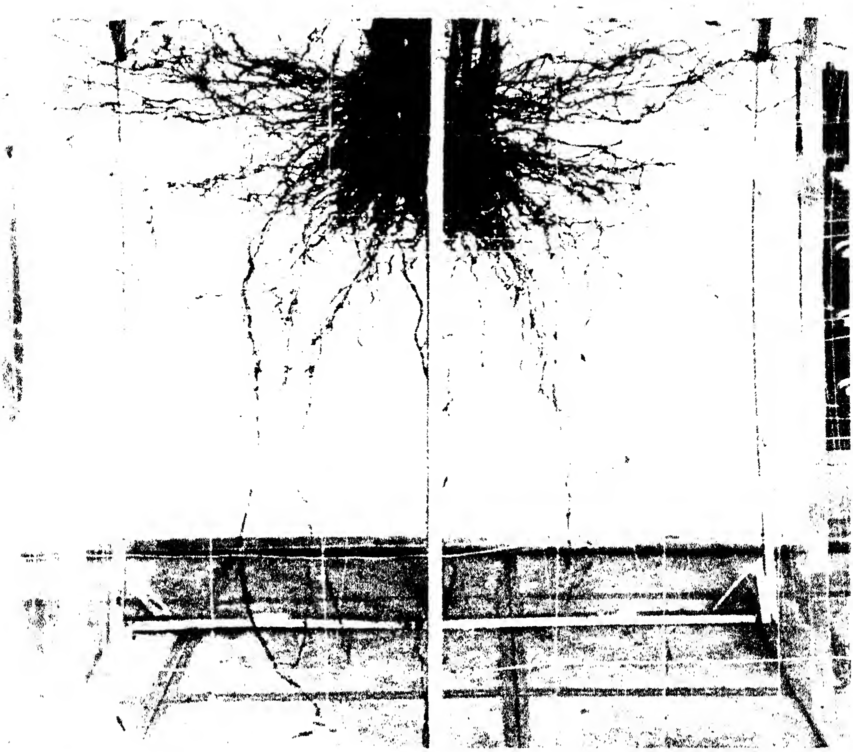

FIG. 1. The Root-system of a First-nobilized Glagah seedling

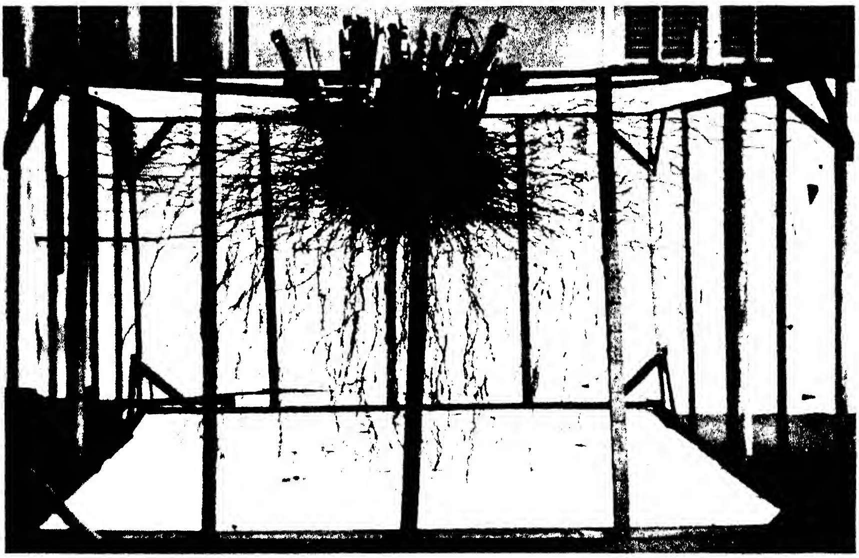

FIG. 2. Root-system of a POJ. 2878 × Uba Marot seedling

THE AGRICULTURALLY IMPORTANT SOILS OF BURMA

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BURMA is the largest province of the Indian Empire; excluding the Shan States and Karenni State, it occupies 184,102 square miles. A great deal of this area is covered by forests. The cultivated area was 17·2 million acres in 1933–4 [1], and in it alluvial soils vastly preponderate.

Inspection of a physical map of Burma will show that the country may be divided into: (1) the narrow Arakan coastal strip; (2) the Arakan Yoma mountain range and its extensions to the north and south; (3) the central belt consisting of the basins of the Rivers Chindwin, Irrawaddy, and Sittang; (4) the Shan Plateau and the mountains extending north and south from it; and (5) the narrow coastal strip in the south-east consisting of the Tenasserim Division [2].

Except for small areas in the coastal strips and the Shan Plateau, the important agricultural soils of Burma are situated in the central belt.

Climate [3].—The central belt can be divided into three portions on the basis of rainfall: (*a*) the northern region, roughly between 23° N. and 26° N., receives an annual rainfall of 40–90 in.; (*b*) the middle portion, known as the Dry Zone, between latitudes 23° N. and 19° N., with an annual rainfall of 20–40 in.; and (*c*) the southern portion, lying between latitudes 19° N. and 15° N., and receiving 80–200 in. of rainfall annually. This portion includes the whole of the Irrawaddy Delta and the basin of the River Sittang.

The rainfall of Burma is almost entirely derived from the south-west monsoon and is therefore practically confined to the period April to October. The greatest fall is in June to September. The rains cause severe floods and it is common to have immense areas of cultivated land under water in the rainy season.

The temperature is highest during April and May, reaching 100° F. or more in parts. When the rains set in the temperature falls somewhat but still remains high. During November the temperature begins to fall still further and remains low during the period November to February, at the end of which it rises again.

Topography.—For 200 miles south of Myitkyina in the extreme north of the northern section, the agricultural land lying between the hills on either side of the railway and rivers is barely more than 10 miles wide, and it is only in the southern 100 miles that the valleys widen to a gently undulating plain some 30 miles wide. The Dry Zone is a low-lying plain much cut up by ravines. The southern section is also a level plain, except for the Pegu Yoma Range, which divides the basins of the Irrawaddy and the Sittang rivers.

Floods are therefore frequent throughout the central belt. The principal railway line runs from Myitkyina in the extreme north to Rangoon in the south. The line follows the river valleys, so that breaches in the railway line during the rainy season are a common occurrence in Burma.

The low-lying soil of the whole belt is almost uniformly fine-textured,

so that drainage by percolation is practically non-existent. The only possible means of drainage is by surface run-off. The level topography restricts even this form of drainage. The result is that extensive areas are waterlogged during the rains. These areas are therefore suited only for the growth of paddy.

Geology [4].—In the northern section of the central belt small areas are occupied by old hard rocks, chiefly granite, gneiss, and limestone. The bulk of the belt is, however, covered by alluvium. The texture of the alluvium is generally heavy, although sandy material occurs in places, especially near the river banks ('non mye,' i.e. riverine silts).

The Soil Types

A systematic study of the soils of Burma from the standpoint of pedology has not been made. The information gathered so far has been obtained in studies of soil fertility and in advisory work. For practical reasons the soils that have been studied in the central belt were taken from places not far from the railway line. Large areas to the west of the Irrawaddy have not yet been studied.

The soils of the central belt may be classified as follows:

A. Soils with Impeded Drainage—

- 1*a*. Formed in arid climate, and containing calcium carbonate accumulation in the profile ('regur'). These approach the Solontschak type, e.g. in Mandalay, Singaing.
- 1*b*. Similar to those in 1*a* but with a slight accumulation of sodium salts, e.g. in Padu.
- 2. Formed in a wet climate with a rainfall of 80 in. or more, e.g. in Hmawbi.

B. Soils with Good Drainage—

1. Formed in an arid climate, e.g. Padu (Red), Kanbalu. The molecular ratio SiO_2/Al_2O_3 for the clay-fraction of these soils is greater than 2·0. They are therefore non-lateritic, and are probably akin to the red earths.
2. Formed in a wet climate with a rainfall of 80 in. or more. The clay-fraction of such soils shows a SiO_2/Al_2O_3 molecular ratio ranging between 1·7 and 2. These soils are therefore lateritic [5].

Analytical Methods

The composition of the whole soils was determined by boiling with conc. HCl for 8 hours on the sand-bath and analysing the extracts. The clay-fraction was separated by treatment with sodium hypobromite followed by dispersion with ammonia. The sedimentation was carried out in beakers, the clay being poured off to a depth of 8·4 cm. after standing for 24 hours. After flocculation with dilute HCl, the clay was filtered off, dried, and analysed by fusion with sodium carbonate in nickel crucibles. Only routine methods were used in the determinations. No great accuracy is therefore claimed for the silica—sesquioxide or silica—alumina ratios of the clay-fraction. All such ratios given in the various Tables are molecular ratios.

DESCRIPTION OF TYPES

A. Soils with Impeded Drainage

1*a*. *Formed in an arid climate.*

Mandalay Soil: Latitude 22° N.; longitude 96° 5′ E.
Geology: Recent Alluvium. Very deep.
Rainfall: 30 in. Drainage poor.
Topography: Level.

Soil pits show this soil to consist of a dark humus-containing horizon about 3 ft. deep, with small light-coloured nodules of calcium carbonate. This horizon is grey or greyish-black when dry and almost black when moist. At about 3 ft. depth the humus-layer ceases and is replaced by a yellow horizon containing relatively large amounts of calcium carbonate. This horizon extends down to about 8 ft. Below this lies a horizon of yellow clay. The soil was not examined below 12 ft. At 3 ft. 8 in. the nodules were of considerable size, the maximum amount occurring at 4–7 ft., where they form a layer commonly called 'kankar'. Table 1 gives the amount and composition of kankar in the profile [6].

TABLE 1. *Kankar in Mandalay Soil Profile*

Depth in feet	*Stones and gravel 2 mm. diameter (kankar) per cent.*	*Composition of kankar (per cent.)*				
		CaO	MgO	Na_2O	MnO	CO_2
A Horizon						
0–0·5	0·6	39·2	0·2	0·5	0·9	16·5
0·5–1	0·3	39·5	0·3	0·7	0·6	16·1
1–2	1·8	40·9	0·3	1·0	0·8	25·5
2–3	3·3	39·6	0·2	0·8	0·8	16·5
B Horizon						
3–4	8·0	34·2	0·4	2·6	0·6	17·0
4–5	9·8	32·1	0·5	3·5	0·8	18·1
5–6	10·6	33·6	1·2	2·2	1·1	19·9
6–7	7·8	28·3	3·2	1·9	1·1	18·8
7–8	5·5	32·4	1·9	1·2	0·2	18·2
C Horizon						
8–9	3·3	28·2	0·8	1·3	0·2	20·2
9–10	2·6	25·0	0·8	1·3	0·2	19·4
10–11	2·0	26·3	0·8	0·8	0·1	20·6
11–12	2·1	29·3	2·2	0·1	0·2	19·6

The analyses quoted show that the soils of this group belong to the Carbonate Solontschak type. There has been no leaching of humus from the surface-soil downwards, probably because the concentration of electrolytes in the surface-layers is sufficient to prevent it. The B horizon is slightly compacted and contains a considerable accumulation of calcium carbonate. Under paddy-cultivation it has been noticed that the humus-content of the A horizon decreases. The $CaCO_3$-content of the B horizon also decreases.

TABLE 2. *Analysis of Mandalay Soil (Dry Cultivation Area)*

Depth in feet	pH	Soluble in conc. HCl (per cent.) Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	Org. Carbon per cent.	Clay-fraction SiO_2/R_2O_3	SiO_2/Al_2O_3
A Horizon									
0–0·5	8·05	3·26	8·65	0·85	0·91	0·51	0·60	2·24	2·71
0·5–1	8·05	3·34	8·68	1·19	0·88	0·51	0·35	2·16	2·63
1–2	8·22	6·70	8·54	1·35	0·94	0·58	0·23	2·15	2·61
2–3	8·40	4·64	9·58	2·02	0·93	0·87	0·24	2·25	2·73
B Horizon									
3–4	8·65	5·20	9·12	2·71	0·52	0·99	0·22	2·37	2·88
4–5	8·93	5·35	10·34	2·39	1·04	0·86	0·21	2·32	2·82
5–6	9·04	4·96	10·33	2·95	1·54	0·92	0·16	2·31	2·81
6–7	9·09	4·96	10·05	2·64	1·71	0·98	0·18	2·23	2·75
7–8	9·10	4·92	9·28	2·12	1·67	0·99	0·14	2·28	2·81
C Horizon									
8–9	9·00	5·15	9·51	1·28	1·62	0·99	0·09	2·19	2·69
9–10	8·86	5·15	9·39	0·83	1·51	0·75	0·09	2·07	2·60
10–11	8·68	4·92	9·42	0·72	1·25	0·86	0·08	2·02	2·47
11–12	8·68	5·63	9·07	0·65	1·42	0·96	0·05	1·92	2·29

The soils in the Dry Zone have been cultivated for long periods, so that profile-development under natural conditions has been hindered. These soils crack very strongly in the rainless months, the cracks being several feet deep. This behaviour again prevents a normal development in the profile. Vageler states [7] that these cracks in tropical soils tend to render them homogeneous by circulation.

The Mandalay soil type bears a close resemblance to the black-cotton soil of India [8].

Singaing Soil: Kyauksé district: Latitude 21° 45′ N.; longitude 96° 9′ E. On the railway line.
Geology: Recent Alluvium.
Rainfall: 30 in.
Topography: Level.

TABLE 3. *Analysis of Singaing Soil*

Depth (inches)	0–13	13–26	26–48
Coarse sand %	2·70	1·30	1·25
Fine sand %	21·00	19·05	19·55
Silt %	23·18	24·48	24·35
Clay %	43·05	46·20	46·30
pH	8·5	8·2	8·7
CaO % sol. in HCl	4·15	3·14	3·43
MgO % „ „	1·48	1·69	1·75
Na_2O % „ „	0·76	0·98	0·97
SiO_2/R_2O_3 in clay-fraction	2·28	2·31	2·39
SiO_2/Al_2O_3 „	2·82	2·81	2·90

A. 1*b*. ***Soils with impeded drainage formed in an arid climate and showing the presence of sodium salts.***

Padu Black Soil: Sagaing district: Latitude 22° 5′ N.; longitude 95° 58′ E.; situated on the railway line from Mandalay to Myitkyina.

Geology: Recent Alluvium.

Rainfall: 25 in. Drainage poor.

Topography: Level.

The Padu Black soil is a very stiff tenacious clay that forms deep cracks in the dry season. The chief crops are gram and wheat. This soil is cultivated in the dry spells from July onwards. Round Padu Lake the cultivators may never be able to start until October owing to poor drainage, but such a method of working is exceptional. Actually most of the cultivation is done during the rains. Crops are not sown, however, until the end of the rains.

The Padu Black soil is blacker in colour when wet than is the Mandalay soil. The water-extract of the Padu Black soil contains organic matter in solution, an indication that the soil contains much exchangeable sodium, whereas the water-extract of the Mandalay soil does not contain organic matter, probably because this soil is rich in exchangeable calcium. The analysis of Padu soil (Table 4) shows the relatively high content of sodium compared with that of calcium.

TABLE 4. *Analysis of Padu Black Soil*

Depth (inches)	*0–6*	*6–24*	*24–48*
Coarse sand %	12·5	11·3	10·5
Fine sand %	9·7	10·6	10·3
Silt %	15·3	15·2	14·8
Clay %	56·0	57·6	59·0
pH	7·85	7·95	8·25
CaO % sol. in HCl	0·88	0·80	0·64
Na_2O % ,, ,,	0·97	1·03	1·31
Organic carbon %	0·43	0·40	0·34
Nitrogen %	0·05	0·04	0.04
SiO_2/R_2O_3 in clay-fraction	2·43	2·44	2·57
SiO_2/Al_2O_3 ,,	2·97	3·01	3·17

Chiba Soil: Shwebo district: Latitude 22° 34′ N.; longitude 95° 54′ E. About 3 miles south-west of Shwebo town.

Geology: Recent Alluvium.

Rainfall: 30 in. Drainage fair, as the soil is coarse-textured.

Topography: Level.

The soil is a sandy loam showing saline inflorescence in the dry season. Such saline soils are common near Shwebo and are known as 'hsatpya'. The chief constituent seems to be sodium sulphate.

There is a striking difference between the soils in the southern portion of the Dry Zone and those in the northern portion, the dividing line between the two portions being the River Irrawaddy. The soils in the south, e.g. Mandalay and Singaing, are rich in calcium and magnesium and relatively low in sodium. On the other hand, the soils in the northern

portion of the Dry Zone, e.g. Padu Black and Chiba, are low in calcium and magnesium but contain a relatively high proportion of sodium. Saline inflorescence is common in this area, the chief salts being sulphates, although the soil of the Chiba farm does not show this inflorescence.

TABLE 5. *Analysis of Chiba Soil*

Depth (inches)	*0–9*	*9–28*	*28–40*	*40–48*
Coarse sand %	42·9	41·8	35·0	38·1
Fine sand %	24·3	20·8	29·7	25·8
Silt %	13·0	14·1	12·3	13·2
Clay %	18·5	21·8	18·5	21·8
pH	6·6	7·85	9·1	9·1
CaO % sol. in conc. HCl	0·20	0·33	0·40	0·46
Na_2O % ,, ,,	0·39	0·42	0·48	0·37
SiO_2/R_2O_3 in clay-fraction	2·64	3·05	3·02	3·06
SiO_2/Al_2O_3 ,,	3·17	3·69	3·66	3·72

A. 2. *Soils with impeded drainage formed under a high rainfall.*

Hmawbi Paddy Soil: Latitude 17° 6′ N.; longitude 96° 5′ E. On the railway line from Rangoon to Prome.

Geology: Old Alluvium.

Rainfall: 95 in. Marshy conditions from May to November; the permanent water-table is only 7½ ft. below the surface.

Topography: Level.

TABLE 6. *Analysis of Hmawbi Paddy Soil*

Depth (feet)	*0–0·5*	*1–2*	*4–5*	*6–7*	*7–8*	*8–9*	*9–10*	*10–11*	*11–12*
Coarse sand %	1·3	1·4	0·9	0·5	0·5	2·5	4·4	14·9	7·1
Fine sand %	10·2	8·5	5·9	5·1	6·2	12·1	17·9	21·4	24·4
Silt %	60·7	42·9	35·8	41·0	40·4	41·2	38·7	34·9	34·5
Clay %	24·5	45·3	53·5	48·8	47·0	40·6	34·5	26·9	30·6
pH	5·6	5·4	6·05	6·15	6·25	6·25	6·05	5·5	5·5
Al_2O_3 % sol. in conc. HCl	5·3	9·1	11·6	11·7	11·4	10·1	7·6	6·8	7·7
CaO % ,, ,,	0·15	0·21	0·22	0·19	0·26	0·21	0·16	0·13	0·13
MgO % ,, ,,	0·13	0·17	0·55	0·44	1·28	0·92	0·45	0·31	0·25
SiO_2/R_2O_3 in clay-fraction	1·97	2·12	1·88	2·16	2·04	2·08	2·16	2·13	2·96
SiO_2/Al_2O_3 ,,	2·14	2·34	2·11	2·58	2·58	2·54	2·43	2·44	2·20
Total exchangeable bases in m.eq. held by 100 gm. of soil	5·9	11·3	18·1	19·6	12·7	12·3	8·8	5·6	4·9

TABLE 7. *Analysis of Hmawbi Soil from Grazing Ground (Uncultivated)*

Depth (feet)	*0–0·5*	*0·5–1*	*1–2*	*2–3*	*3–4*	*4–5*	*5–6*
Coarse sand %	0·8	0·8	1·5	1·8	3·9	9·7	52·5
Fine sand %	19·1	15·5	15·2	14·5	38·9	66·6	43·0
Silt %	32·7	31·3	35·5	41·7	28·9	11·0	2·6
Clay %	41·4	47·1	43·0	39·3	25·4	11·4	1·9
pH	5·65	6·05	7·2	7·5	7·25	6·6	6·5
Al_2O_3 % sol. in conc. HCl	9·9	9·3	11·5	11·8	8·7	5·5	3·2
Fe_2O_3 % ,, ,,	3·7	4·6	6·1	6·5	5·3	3·9	2·3
Organic carbon %	1·79	1·34	0·67	0·39	0·29	0·15	0·05
Nitrogen %	0·16	0·11	0·06	0·04	0·04	0·02	0·01
SiO_2/R_2O_3 in clay-fraction	2·18	2·04	1·97	2·14	2·08	..	2·15
SiO_2/Al_2O_3 ,,	2·52	2·36	2·34	2·61	2·52	..	2·60
Exchangeable bases per cent. in m.eq.	12·5	20·3	20·3	25·0	21·1	11·0	6·1

The Hmawbi soil (Table 6) is the typical paddy soil of the Delta of the Irrawaddy, and hence is by far the most important type of soil in Burma. This soil cracks in the dry weather just like the soil of the Dry Zone (Mandalay, Padu). The dry surface-soil is a light yellow, becoming a deeper yellow in the B horizon. The permanent water-table is at about 7½ ft. below the surface. Near this zone and below, the soil has a bluish colour due to the presence of ferrous iron, probably in the form of sulphide. This is the only obvious horizon change, because organic matter shades imperceptibly.

The B horizon is more compact than the A and C horizons, probably owing to the transfer of finer material from the surface. The B horizon is also a zone of concentration (cf. the data for pH, Al_2O_3 and Fe_2O_3 soluble in HCl, and exchangeable bases). This concentration would be expected from the heavy rainfall, which would cause a downward leaching, and from the capillary rise from the water-table in the C horizon in the dry season. These two movements are likely to be impeded by the heavy-textured B horizon.

B. 1. *Soils with good drainage formed under an arid climate.*

This type of soil occurs in the Dry Zone. The improved drainage is caused by the location of such soils on slopes and by their coarse texture. When the soil is deficient in organic matter its colour is red (Padu Red), but when sufficient organic matter is present the colour is dark (Kanbalu). The improved drainage is reflected in the pH values, which indicate a neutral or slightly acid reaction, instead of the decided alkaline reaction shown by the associated soils with impeded drainage.

TABLE 8. *Analysis of Padu Red Soil*

Depth (inches)	*0–6*	*6–24*	*24–48*
Coarse sand %	55·0	39·2	29·4
Fine sand %	33·1	21·4	22·3
Silt %	4·3	6·4	9·6
Clay %	8·8	33·2	36·4
pH	6·1	6·1	6·7
Organic carbon %	0·17	0·29	0·23
Nitrogen %	0·04	0·06	0·05
Al_2O_3 % sol. in conc. HCl	1·77	8·52	8·48
CaO % ,, ,,	0·08	0·18	0·24
Na_2O % ,, ,,	0·21	0·43	0·33
SiO_2/R_2O_3 in clay-fraction	2·13	1·89	1·91
SiO_2/Al_2O_3 ,,	2·62	2·29	2·28

Kanbalu Soil: Latitude 23° 12′ N.; longitude 95° 35′ E. Situated on the railway line from Mandalay to Myitkyina, between the River Mu and the River Irrawaddy.

Geology: Recent Alluvium.

Rainfall: 45 in. Drainage good.

Topography: Undulating.

TABLE 9. *Analysis of Kanbalu Soil*

Depth (inches)	*0–13*	*13–25*	*25–37*	*37–48*
Coarse sand %	57·7	44·0	36·9	40·8
Fine sand %	15·0	13·1	17·9	29·2
Silt %	6·4	5·6	11·4	9·7
Clay %	20·0	33·5	30·9	18·9
pH	6·15	6·05	6·5	6·2
Organic carbon %	0·68	0·42	0·27	0·17
Nitrogen %	0·07	0·05	0·05	0·04
Al_2O_3 % sol. in conc. HCl	5·1	9·0	9·0	8·8
CaO % ,, ,,	0·20	0·25	0·62	1·16
Na_2O % ,, ,,	0·05	0·50	0·58	0·55
SiO_2/R_2O_3 in clay-fraction	2·47	2·14	2·29	2·38
SiO_2/Al_2O_3 ,,	2·98	2·53	2·71	2·88

The SiO_2/Al_2O_3 ratios in the soil type represented by Padu Red and Kanbalu are higher than 2. These soils may be regarded as akin to the red earths [7, 9].

B. 2. *Soils with good drainage formed under a heavy rainfall.*

These soils are of the lateritic type. They are found in the Irrawaddy Delta and in the coastal strips receiving a heavy rainfall. The water-table in these soils is very far below the surface or does not exist at all. In fact laterite-formation appears to cease at the water-table. The drainage is favoured by their location on slopes. Soils of this type are highly leached, as may be seen from the very low percentages of exchangeable and acid-soluble bases, and the high acidity, as indicated by low pH values (Tables 10, 11). These soils are usually adapted to the growth of rubber and fruit-trees or evergreen forest.

TABLE 10. *Analysis of Hmawbi Garden Laterite Soil*

Depth (feet)	*0–1*	*1–6*	*6–9*
Coarse sand %	56·3	38·8	37·6
Fine sand %	19·3	23·8	23·0
Silt %	7·7	10·1	14·2
Clay %	15·0	27·3	24·1
pH	5·3	5·3	5·2
Al_2O_3 % sol. in conc. HCl	4·04	8·21	8·18
Fe_2O_3 % ,, ,,	1·24	2·21	3·89
CaO % ,, ,,	0·02	0·03	0·03
MgO % ,, ,,	0·01	0·02	0·02
SiO_2/R_2O_3 in clay-fraction	1·71	1·75	1·58
SiO_2/Al_2O_3 ,,	2·01	2·03	1·76
Exchangeable bases per cent. in m.eq.	2·0	1·5	2·0

The SiO_2/Al_2O_3 ratios of the clay-fraction of this type of soils range between 1·7 and 2·0. The soils can therefore be regarded only as lateritic. Probably the absence of rains for 6 months in the year prevents the formation of laterite.

TABLE 11. *Analysis of Hmawbi Virgin Laterite (Evergreen Forest)*

Depth (feet)	*0–1·15*	*1·75–3*	*3–4*	*13–14*	*23–24*
Coarse sand %	24·8	19·7	10·7	34·9	43·8
Fine sand %	50·5	34·7	42·1	26·4	31·0
Silt %	9·4	17·1	16·5	13·8	17·9
Clay %	14·5	27·7	29·7	24·4	6·3
pH	5·1	5·4	5·3	5·35	5·5
Al_2O_3 % sol. in conc. HCl	4·32	8·93	8·53	9·88	7·37
Fe_2O_3 % ,, ,,	1·43	4·06	4·36	3·82	3·10
CaO % ,, ,,	0·06	0·03	0·03	0·02	0·02
MgO % ,, ,,	0·07	0·12	0·12	0·02	0·02
SiO_2/R_2O_3 in clay-fraction	1·60	1·61	1·60	1·63	1·49
SiO_2/Al_2O_3 ,,	1·92	1·86	1·87	1·84	1·85
Exchangeable bases per cent. in m.eq.	1·2	2·1	1·5	1·7	1·2

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SOME EFFECTS OF DROUGHT ON POTATO TUBERS

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With Plates 14, 15

Introduction.—During the dry summer of 1933 potato plants showed many indications of injury from drought at Glasnevin. The plants (variety Up-to-Date) in a spraying experiment consisting of many small plots all appeared pale and somewhat wilted in August and September, but the 26 randomized plots sprayed with proprietary mixtures and the 5 unsprayed plots obviously suffered more than the 13 plots sprayed with Burgundy mixture. This was mainly due, not to the better blight control in the last case, but to the slightly stunted leaf-apparatus of the plants withstanding the drought better than the initially more luxuriant foliage on the other plants.

These plots consisted of three drills bounded by a vacant drill on each side, and the effect of the drought was also shown by the more luxuriant appearance of the outer drills and their higher yield, which amounted to 27 per cent. on the average. This contrast occurred throughout the plots, although it was least marked where Burgundy mixture had been used, and was due to the greater amount of root-run provided for the outer plants and the additional water thus made available. On one only of the 32 plots did a centre drill give a higher yield than either of the outer ones. The same phenomenon is observable in other years, but to a less extent, because soil moisture is not usually a limiting factor.

These observations make clear the serious nature of the water-shortage in the latter part of 1933. There were two hot and dry periods, viz. from the end of July to about Aug. 22, and from early September to Sept. 17, and the effect on the foliage was most severe at the end of these two periods. The effects, however, were not confined to the foliage, for the tubers also were proved to have been affected by the drought. The weather of 1933 is shown in Table 1. The summers of 1934 and 1935, apart from September, were also dry, and as potatoes showed some drought effects in these years also, weather records referring to them are included in the table.

Experimental

With particular reference to Tuber-softening and Premature Sprouting

In digging an adjacent plot of President potatoes on Sept. 28 and 29, 1933, most of the plants, approximately 250 in number, had apparently normal tubers, but those belonging to about 10 plants were perceptibly soft. Usually all the tubers of a plant were affected, more especially the larger ones, but sometimes only a single tuber was abnormal. The softness was not due to decay, for microscopic examination and cultural experiments showed that parasites were absent. The tubers came out of the ground dry and clean, unlike those affected by such diseases as pink rot and black leg, which also give rise to soft tubers, and most of

them were still attached to the stalk by sound stolons. The softness was in some cases confined to the heel-end, but in others the whole tuber was involved. Usually it was necessary to handle the affected tubers, which had a rubbery feel, before their condition was discovered, but

TABLE 1. *Weather Records at Glasnevin 1933, 1934, 1935*

	Shade temp. (° F.)			*Rainfall* (mm.)		*Sunshine* (hours)	
Period	*Absolute max.*	*Mean*	*Deviation*	*Total*	*Deviation*	*Daily mean*	*Deviation*
1933 June	75	57·8	+1·6	40	−11	4·77	−1·53
July	81	63·1	+3·9	48	−17	5·52	+0·04
Aug.	79	62·1	+3·6	18	−64	6·25	+1·02
Sept.	75	57·7	+2·9	22	−29	5·13	+0·50
1934 June	77	59·3	+3·5	39	−12	6·76	+0·57
July	80	63·0	+3·6	46	−19	7·01	+1·46
Aug.	75	58·7	0·0	81	−1	4·66	−0·36
Sept.	72	57·1	+2·2	78	+27	4·78	+0·35
1935 June	76	57·7	+1·9	73	+22	5·74	−0·45
July	79	60·9	+1·5	21	−44	6·94	+1·39
Aug.	77	60·9	+2·2	58	−24	5·34	+0·32
Sept.	69	55·5	+0·6	97	+46	4·14	−0·29

others were visibly shrivelled. Most of the plants which produced these tubers were dead at the time of digging, but a few were still green and the majority were known to have suffered from virus diseases, for the potatoes belonged to a poor commercial lot. In addition to some leaf-roll and various mosaics, the principal virus present was a yellow mosaic related to the tuber blotch virus of Loughnane and Clinch [1], which spread considerably during the year. It is concluded on other grounds that this affects transpiration, and as it was certainly present in the worst cases, though not in all, it appears to have been an aggravating factor.

Drought was clearly the cause of the injury. Certain plants in their extreme need had drawn on the water-supply of the tubers, no doubt in order to eke out the existence of the aerial parts, but most of them had died in spite of this. That the water-loss took place in this way (through the stolons and into the stalks) and not through the periderm into the soil was shown by its typical occurrence in the older tubers with the thickest skins, by the localization of the softness to the heel-end, and also by the fact that all the tubers of a plant and all the plants were not equally affected. The soil appeared about equally dry throughout, and although some water can undoubtedly be lost through the periderm if the soil is dry enough, this cannot have been the main channel, or the majority of the tubers would have been more uniformly affected. That the injury was confined to so few plants is probably attributable to their having suffered most from the drought due to a combination of causes, including virus-infection leading to inability to control transpiration, proximity to a hard, trodden path, and other unexplained variations in soil moisture.

Although the softening was confined to certain plants, there was a gradual and imperceptible transition to plants with normally hard tubers,

and it was impossible to draw a line where the injury stopped. This was made clear after the crop was placed in a cool potato-store, in separate units, following careful hand-digging, for the tubers of a large proportion of the plants which appeared normal when dug softened to an unusual extent, and frequently sprouted, during October and November, while those of other plants did not do so. The relatively enormous loss in weight which the very soft tubers suffered is shown below, but the slight generalized loss was probably greater in the aggregate. It is concluded that this represents what occurred in the spraying experiment referred to later.

Absorption of water by soft tubers.—Immediately after digging, experiments were begun to determine the subsequent behaviour of the soft President tubers. The first preliminary test was started four days after digging, and was designed to determine to what extent these tubers were deficient in moisture and the rate at which water was taken up. Two soft tubers, as dug (No. 1 being very soft and shrivelled, No. 2 very soft but not shrivelled), and two normal tubers from the same plot were weighed and placed in moist soil (all in the same vessel) at room-temperature, and were afterwards removed and weighed at weekly intervals. The results are shown in Table 2 and Text-fig. 1.

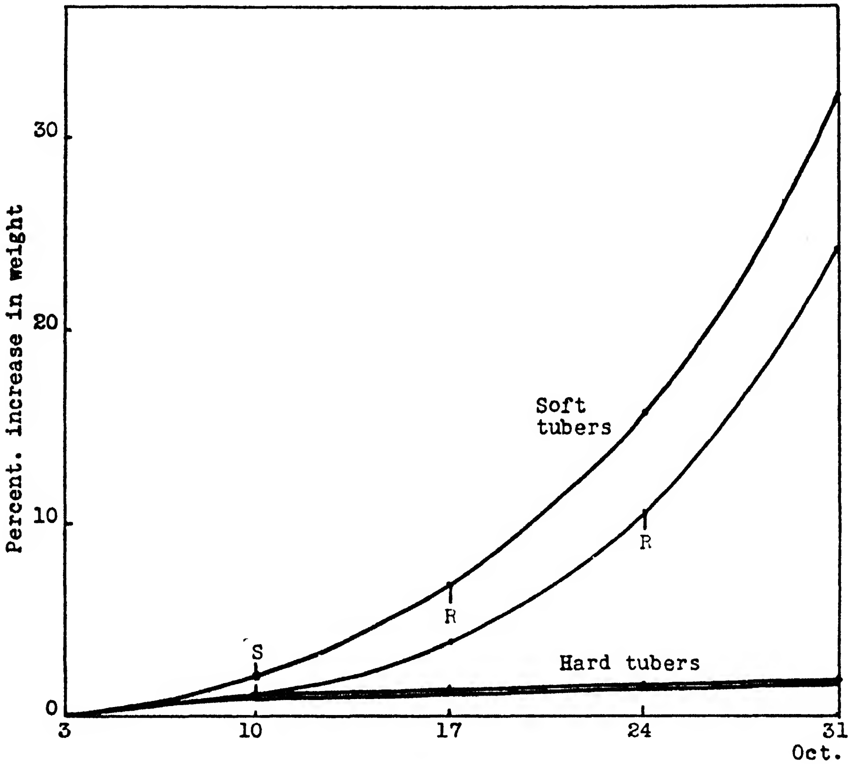
TABLE 2. *Water-absorption and Sprouting of Soft and Firm Tubers*

Tuber condition	*Date 1933*	*Weight in grammes*		*Increase per cent.*		*Remarks*
		Tuber 1	*Tuber 2*	*Tuber 1*	*Tuber 2*	
Soft	Oct. 3	56·7	50·2	100·0	100·0	
	10	57·9	50·7	102·1	101·0	Sprouts present
	17	60·7	52·1	107·1	103·8	Roots began
	24	65·7	55·6	115·9	110·8	Roots present
	31	74·9	62·4	132·1	124·3	Practically firm
Hard	Oct. 3	66·4	62·1	100·0	100·0	
	10	67·2	62·8	101·2	101·1	
	17	67·4	63·1	101·5	101·6	
	24	67·5	63·2	101·7	101·8	
	31	67·6	63·3	101·9	101·9	No sprouts or roots

The two soft tubers began to show sprouts from most of their eyes within a week (Oct. 10), and within three weeks these sprouts were up to 2·5 cm. long, and at that time well-developed roots were present. The soft tubers began to absorb water rapidly so soon as they were put in moist soil, and more rapidly still in the 2 or 3 weeks following the appearance of sprouts and, especially, of roots (marked by S and R in Text-fig. 1). The average increase in weight (which, neglecting respiration, practically represents the amount of water taken up) was 28·4 per cent. of the original weight within a period of 4 weeks (to Oct. 31). The normal tubers on the other hand did not show any sign of sprouting until Dec. 5, when the sprouts on the originally soft tubers were over 5 cm. long; they took up very little water (1·9 per cent.) during the 4 weeks, and, unlike the soft tubers, absorbed more than half of this in

the first week and from 70 to 76 per cent. in the first fortnight, after which the up-take was very slow. The appearance of these tubers on Dec. 5 is shown in Fig. 1, Plate 14.

The idea underlying the first experiment was that perhaps the soft tubers might absorb water in moist soil until an end-point was reached and they became hard again, thus giving a measure of the amount of water they had previously lost. Actually this never happens at ordinary



S = sprouts appeared. R = roots appeared.

FIG. 1. Water-absorption and sprouting of two soft and two hard President tubers in moist sand immediately after digging (1st experiment).

temperatures, for although water is absorbed slowly through the skin, most of it is taken up in the hastened sprouting that always ensues. Hence all that can be said is that some three weeks after sprouting and one to two after rooting, two very soft tubers had become almost normally hard again, and shrivelling (where present) had disappeared. At this point an average of 28·4 per cent. of water had been absorbed, but some of it had gone to produce sprouts and roots. This was confirmed in later experiments, for it was found that very soft tubers had to absorb between 30 and 40 per cent. of their original weight (during the process of which they sprouted) before becoming fully firm again.

Experiments conducted in 1935 showed that when just perceptibly soft freshly dug tubers were placed in moist sand at 0°–2° C. they

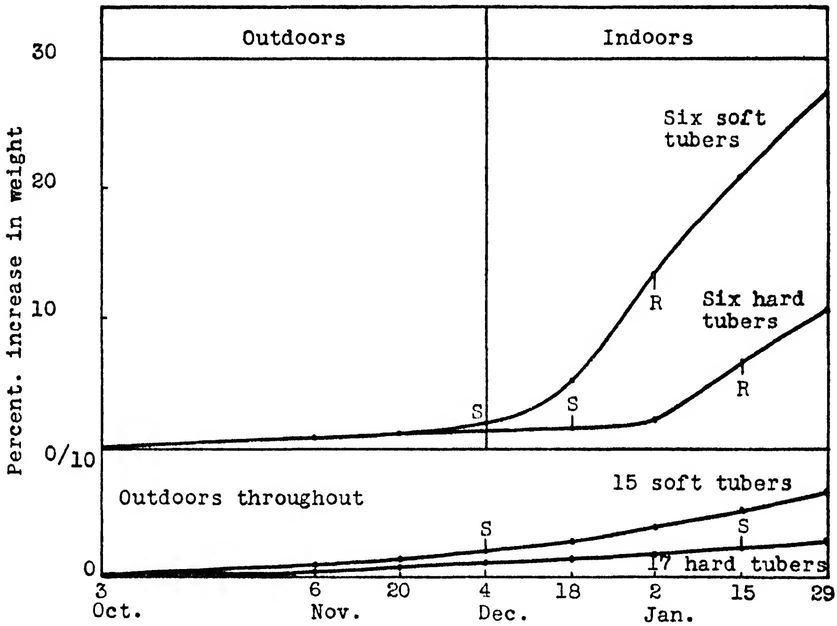
became firm again in 4 weeks (without sprouting) after absorbing 2·5–3 per cent. of their original weight of water. Hence a loss of water of this magnitude must make a noticeable change in tuber firmness. Under somewhat similar conditions, tubers designated 'softish' and 'soft' respectively, absorbed 6·2 and 12·4 per cent. of their original weights of water before becoming about normally firm again, while very soft tubers absorbed considerably more. These figures give a measure of the water-deficiency in soft tubers in the field.

The original experiment was repeated later in many forms in 1933 and 1935, with the same general result. The sooner the experiments were begun after digging, and the softer the tubers, the greater was the contrast both in water up-take and premature sprouting. Absorption by the soft tubers was always faster from the beginning, the rate increasing after sprouts and roots began to appear, and early sprouting occurred in direct proportion to the initial water-deficiency. It is not necessary to detail the work, but in one repetition, carried out in Dec. 1933 and Jan. 1934 in sand moistened with tap water, one very soft sprouted tuber increased in weight by as much as 31·6 per cent. in 6 weeks, and the average increase was 7·9 per cent., compared with maximum and average increases of 4·3 and 2·5 per cent. for hard tubers. In another similar contemporaneous experiment lasting for 4 weeks the average percentage increase in weight of the soft tubers was 26·5, and that of the hard tubers 6·7 per cent., and similar results were again obtained in 1935. In all cases the soft tubers sprouted in advance of the normal ones, so long as the temperature was suitable, the time-difference being about 2 weeks in mid-winter.

Effects of temperature.—The relationship of temperature to increase in tuber-weight, sprouting, and root-development, is illustrated in Text Fig. 2. In this experiment (*a*) 25 soft tubers, (*b*) 25 hard tubers from normal plants, and (*c*) 25 hard tubers from plants which produced some soft tubers, were placed in moist sand in the open. As lots (*b*) and (*c*) reacted similarly, the latter is excluded from the figure. After nine weeks progress was found too slow and one-third of each lot (1 pot) was brought into the laboratory (see upper part of Text-fig. 2), the remainder being left outside (lower part of Text-fig. 2). The weight-curves for soft and hard tubers generally follow the same courses at first as in Text-fig. 1, the former rising gradually and the latter running almost horizontally. But whereas in the first experiment the curve for the hard tubers appeared to diverge completely from the other, in the second the two curves eventually followed a similar course, but separated by an interval in time averaging 4 weeks. In other words, while early in the resting period only the soft tubers sprouted and took up any appreciable quantity of water, later on both soft and hard tubers did so, but at unequal rates, the soft tubers absorbing eventually 2–3 times as much water as the normal ones. The same events took place at a slower rate when tubers sprouted outside during the winter (Text-fig. 2, lower part). These tubers sprouted slowly and produced no roots during the experimental period.

There is abundant evidence that sprouting and water up-take are

accompanying and non-separable phenomena, for the weight jumps up when sprouts appear, and still more so when roots develop some 2, 4, 6, or more weeks later, depending on temperature, season, and tuber individuality. The remaining experiment, which relates to soft tubers only, makes this clear. It was carried out somewhat later (Nov. to Jan. 1933–4) and included 4 lots of 10 tubers each, which were put to sprout in moist sand at 20°, 15°, 10°, and 5° C., each lot including 1 tuber already sprouted and 9 unsprouted. Text-fig. 3 shows the behaviour



S = sprouts appeared on majority of plants.
R = roots appeared on majority of plants.

FIG. 2. Water-absorption and sprouting of soft and hard President tubers in moist sand in mid-winter.

of these at 20° and 15° C., and Text-fig. 4 at 10° and 5° C. The conclusion to be drawn from these Figures is that rapid absorption was a result of rooting, for the two events always followed each other. Sprouting had a less effect, as is shown by the contrast between the initially unsprouted tubers at 10° C. (Text-fig. 4), which sprouted slowly but formed no roots until the close of the experiment, and absorbed only 5·5 per cent. of water in consequence, and the sprouted tuber at this temperature, which rooted in a week and absorbed 47·7 per cent. Evidently 10° C. is a critical temperature which hindered the inception of sprouts but permitted rapid rooting of sprouts already present, and thereby led to an eleven-fold increase in length of the latter, compared with very little growth when roots were absent. The influence of sprouts in promoting absorption in the absence of roots is also shown (Text-fig. 4) by the greater increase in weight of a sprouted tuber at 5° C.

(9·6 per cent.) than of unsprouted ones at 10° C. (5·5 per cent.). The slow increase of unsprouted tubers at 5° C. (3·1 per cent.) was due to absorption through the skin, but they remained soft to the end.

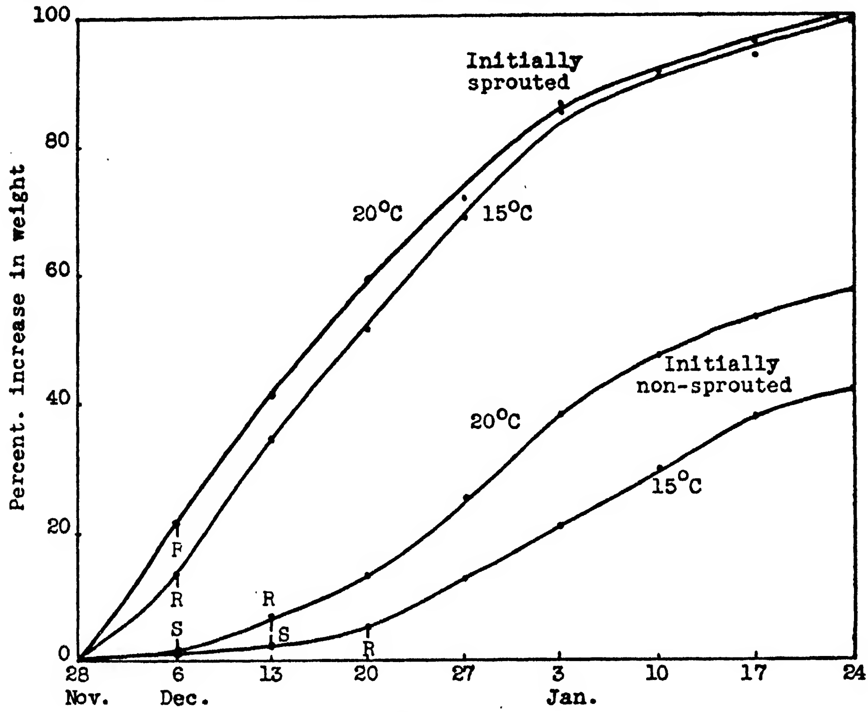
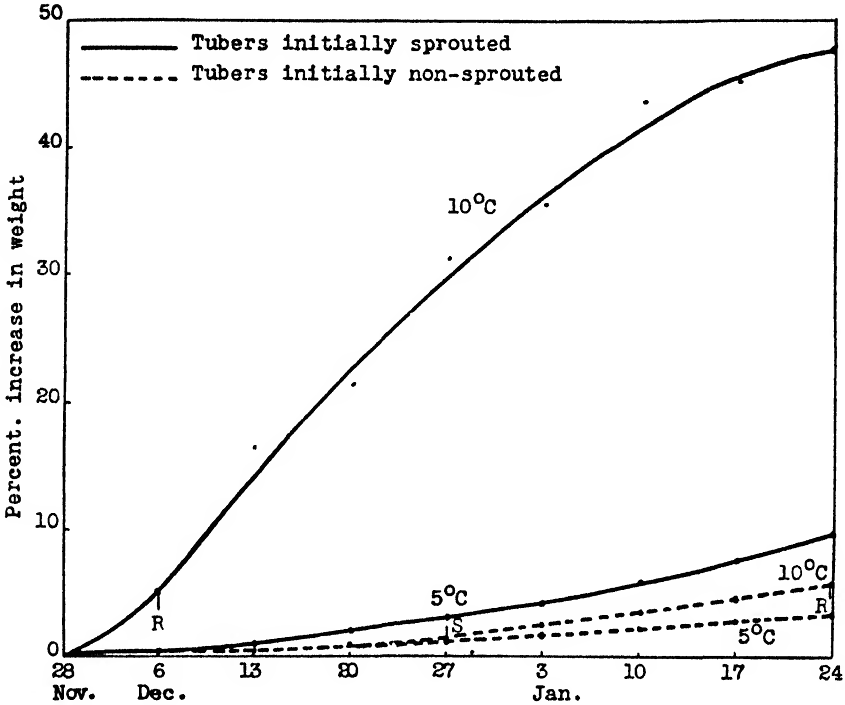


FIG. 3.

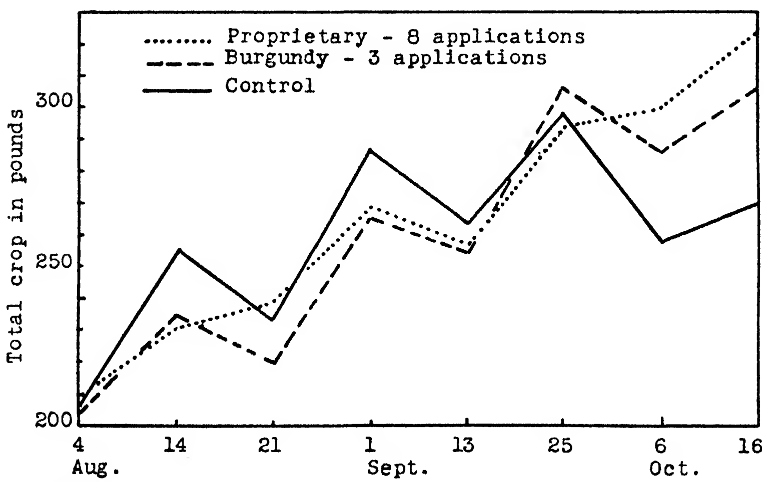
Effect on Yield of Potatoes Dug during Severe Drought

During the drought of 1933 an attempt was made to measure the rate of tuber-formation and to relate it to the development of blight (*Phytophthora infestans*) on the foliage. Three large uniform plots (variety Up-to-Date) were laid down of which one was not sprayed, one was sprayed three times with Burgundy mixture, and one eight times with a proprietary material which had a moderately good effect on blight but little checking effect on the foliage. A portion of each plot was dug at intervals of about 11 days from early August onwards, and the rate of crop increase thereby determined. The yields are shown in Text-fig. 5, and there is the usual evidence of variation due to soil factors, but apart from this it is clear that the three curves rise and fall together, evidently from the same cause. The two principal troughs followed the most serious dry spells and came at a time when the plants were suffering most severely from drought, viz. about Aug. 22 and Sept. 13. No obviously soft tubers were found, but there probably was sufficient generalized water-loss from the tubers to cause a measurable reduction in yield. In the sprouting experiments certain tubers, though not perceptibly soft to the touch, took up more water than usual, and others became soft and sprouted soon after digging. The crop in the spraying experiment was not stored.



Tubers initially sprouted
Tubers initially non-sprouted
Percent. increase in weight
50
40
30
20
10
0
10°C
5°C
R
S
10°C
R
5°C
28
Nov.
6
Dec.
13
20
27
3
Jan.
10
17
24

FIG. 4.



Proprietary - 8 applications
Burgundy - 3 applications
Control
Total crop in pounds
300
250
200
4
Aug.
14
21
1
Sept.
13
25
6
Oct.
16

FIG. 5.

Discussion

Various Forms of Drought-effects on Potato Tubers and their Interrelationships

It has long been known that irregularly shaped potato tubers and other forms of second growth are a feature of dry seasons, e.g. 1868, 1887, 1911, and 1921, and that they often keep badly and sprout abnormally in the following year. The recent dry years in Ireland (1933, 1934, 1935) have afforded opportunity for further study of this question, and it has been found that second growth, or more properly drought-effects, may take many forms. Some five of these have been recognized by previous workers, including Laplaud [2], Martinet [3], Shribaux [4], and McIntosh [5], but actually ten distinct types occur, as follows:

1. Cracking of the tubers as a result of resumed growth in thickness (p. 239).
2. Hollow heart, associated with large tubers and those showing cracking (p. 239).
3. Prolongation of the tuber axis at the rose-end, sometimes associated with glassy end and jelly-end rot (p. 239).
4. Gemmation, consisting of a knob-like outgrowth from an eye borne on a short thick neck which is never stolon-like (p. 240).
5. Chain-tuberization, the secondary tuber or tubers being separated from the primary by a stolon (p. 240).
6. Independent tuber formation taking place to an abnormal extent on new stolons arising from the stem, or on old stolons (p. 241).
7. Premature sprouting in the soil or immediately afterwards, the outgrowths from the tubers becoming stems, which may come above ground, instead of stolons (p. 241).
8. Stem-end wilt, sometimes associated with stem-end rot, and leading to premature sprouting (p. 243).
9. Glassy end and jelly-end rot, often associated with prolongation (p. 243).
10. Drought and heat necrosis (p. 244).

The type of second growth depends on the variety and maturity of the tuber when the rains come [2, 6]. Most of the types are due to resumption of growth after a check, this taking the form either of an increase in size of the original tuber (cracking, hollow heart, and prolongation), or an anticipation of normal sprouting (chain-tuberization and premature sprouting). In other cases the effect is due to drought alone, as in stem-end wilt, there being no true second growth.

It is difficult to separate the effect of drought from that of temperature, since the two generally occur together. The maximum shade temperature recorded for short periods in Ireland (27° C.) is too low to do appreciable harm, and tip-burn is absent, but injury and even death from drought are known. On the other hand, temperature is considered the more important factor in America, and can cause harm in the absence of drought, the tubers being more sensitive than the foliage, but drought without heat is considered harmless [7, 8]. Some American varieties,

e.g. Rural New Yorker, are notably resistant to hot, dry weather, and in NW. Europe potatoes are apparently very susceptible on account of their hygrophytic habit and early growth at low temperature and low insolation.

1. *Cracking* (cf. Fig. 3, Plate 14) is often associated with hollow heart, and certain varieties are susceptible, including Ally, Scottish Chief, Majestic, Irish Queen, Great Scot, Roode Star [5, 9, 10]; Quitte, Ostragis, Goldstärke, Betula, Columba, Feldglück, Feldspende, Goldgelbe in Europe (aut. Volkart), and Rural New Yorker No. 2 under irrigation in America [11]. The cracks are due to resumed growth following a check caused by drought, and they usually heal over. Absence of boron aggravates the injury [12], as do forms of the virus diseases curly dwarf, streak, and spindle tuber [13, 14, 15, 16, 17], as well as rugose mosaic.

Cracking sometimes develops also in the act of digging, or afterwards, in Bliss Triumph [18, 19] and Red King [20], and is attributed to over-turgidity, as when frost kills the foliage but allows root-action to continue. The condition has been reproduced experimentally in the present work by storing freshly dug tubers in moist sand at 0°–2° C. for 6 weeks (Fig. 9, Plate 15), when cracking began, appearing first in a tuber dropped 2½ ft. on to a wooden floor, and later on spontaneously in others. At this stage the tubers had absorbed 4·2–7 per cent. of their weight of water. Macmillan [18] found that when naturally over-turgid tubers lost 6 per cent. in weight they ceased to crack.

2. *Hollow heart* is a disease mainly of large tubers, the optimum soil temperature for which is 18° C. approx. [21], and it predominates therefore in moderately warm potato countries, such as Germany, the northern U.S.A. and Canada, where as much as one-eighth of the crop may be affected. The starch disappears from the central pith, which becomes watery, as in glassy end, and then breaks down, resulting in a lens-shaped or irregular hollow, surrounded by a layer of dead cells, and sometimes a cork layer, which rarely communicates with the exterior [22]. The attack is most severe under irregular irrigation, but it may be common also in dry-land culture when rain follows drought in August or September [11, 23]. Other conditions favouring the attack are small sets, wide spacing, misses, few stalks and tubers per plant, excessive potash which delays maturity, and excessive nitrogen [11, 23, 24, 22; see 25, 24, 26 on the influence of manures on tuber-shape and size]. The attack is frequently associated with cracking and the virus disease, spindle tuber [27, 15]. The following varieties are susceptible: Arran Consul, Irish Queen, Great Scot, Arran Banner, Roode Star, Rural New Yorker No. 2, Allerfrüheste Gelbe [28, 10, 11].

3. *Prolongation* consists of the protrusion of the whole rose-end of a tuber following a stoppage of growth, which results in a constriction or waist (Fig. 6, Plate 16). The new growth is smooth-skinned, and may be nodular at first but generally becomes a symmetrical extension of the original tuber in the direction of its long axis (Figs. 2, 3, Plate 14). Long-tubered varieties are principally affected, including British Queen, King George, Puritan, Catriona, Golden Wonder, and Early Rose [5, 2]. In

the dry seasons of 1934 and 1935 in Ireland it was observed in Arran Cairn (the most susceptible British variety) and Arran Pilot, in association with glassiness, jelly-end rot, and other drought-effects.

The relationship of weather to prolongation is shown by experiments in the hot climate of Ohio on straw-mulching, which prevented second growth in the soil (mainly prolongation), as well as stem-end softening and premature sprouting in storage [29, 30, 31]. The association of softening and premature sprouting is to be observed. The good effects of the mulch are attributed to water-conservation and to reduced soil temperature, leading to more uniform growth. It is to be noticed that, apart from second growth, high soil temperature and abundant moisture lead to the production of long tubers [21, 16], as do spindle tuber and some other virus diseases [27, 15, 32], and certain manures [26, 25].

The new growth is occasionally larger than the old (Fig. 7, Plate 15), resulting in 'bottle-necks' [16]. These cases frequently develop into glassy end and jelly-end rot (q.v.), owing to the transport of materials from the original growth into the new, with the result that the former decays, but in other cases the leaves provide the new materials [33].

4. *Gemmation*, the characteristic second growth of the best potato climates, such as Ireland, and generally the commonest drought-effect [2, 3, 4], consists of the protrusion of a single eye into a knob-like growth situated in the axil of the rudimentary leaf-scar or 'eye-brow', various stages of which are shown in Fig. 4, Plate 15. The gemmae have smooth skins and many eyes and green rapidly on exposure. They are produced during autumn rains following dry summers, or as a result of irregular irrigation, and particularly among susceptible varieties. The disease has been reproduced experimentally by irregular watering and may be aggravated by certain fertilizers, and sometimes also by spraying, which prolongs the life of the foliage [11, 34, 35]. The susceptible varieties include Buchan Beauty, May Queen, Kerr's Pink, British Queen, King George in Ireland and Great Britian; Saucisse, Géante Bleu, Deodara, Arran Victory in Europe [2, 3]; and Burbank, Early Ohio, and Triumph in America [36, 30, 11]. In bad attacks half the crop may consist of second-growth tubers [2, 3].

As in other cases, the materials which make up the gemmae are sometimes derived from the foliage following resumed assimilation and transport after a drought, and sometimes from the primary tubers, in which case the latter may become so light as to be worthless, or they may subsequently produce spindling sprouts and make poor seed-potatoes [3, 2, 6, 37]. The greater part of the minerals is apparently transported from the primary tubers to the secondary in such cases, unlike what happens in normal sprouting [3, 38]. Gemmation is not confined to tubers attached to a living plant, for it can take place after the parent plant dies [33], and in cases of deranged sprouting in storage or after planting [39, 40, 41, 42], which are generally due to a delayed effect of drought.

5. *Chain-tuberization.* Little is known of this condition (Fig. 5, Plate 15) which is regarded as a serious fault. It consists of the production from an eye of one or occasionally more stolons bearing a secondary

tuber, which may produce a further stolon and tertiary tuber, and so on in bad cases more or less indefinitely. The new tubers are usually, but not invariably, small and immature. Irish Chieftain, Northern Star, Kerr's Pink, and Arran Chief are susceptible [9]. Prolongation, gemmation, and chain-tuberization form a series probably indicating a progressive decrease in the capacity for growth of the primary tuber, for in the first the whole rose-end proliferates, in the second the whole of an eye, and in the third a single bud from an eye. A pronounced form of the disease occurs in the virus disease, witches' broom [43, 44].

6. *Independent tuber-formation*, consisting of the production of small new tubers either on fresh stolons or on the old ones, has been noticed particularly in France during autumn rains following drought [4]. The length, number, and branching of stolons increase under conditions favourable to vegetative growth (high temperature, long days, and abundant nitrogen), but under the opposite conditions stolon-growth ceases when the first tubers are set [24], a tendency which is accentuated by lack of potash [12]. When rain follows drought, a further growth by long thick stolons may result [45], and high soil temperature (27°–30° C.) has also been found experimentally to lead to the production of swollen stolons and underground stems [21], a condition which is sometimes found in the field [46].

7. *Premature sprouting in the soil or afterwards.* Sprouting in the soil during summer or autumn, resulting in the production of erect shoots which may come above ground and even produce a second crop of tubers, is very rare in Ireland or Scotland, but was observed in the dry years 1933, 1934, and 1935 in Sharpe's Express, British Queen (twice), Ninety-fold, and an unnamed seedling. The condition is said to be not uncommon in SE. England, in association with tuber-shrivelling, especially in Arran Victory, and also in King Edward, Ballydoon, and Sharpe's Express. It has also been reported in Germany [37], and Connecticut [47], but is more common in warmer countries, such as Jamaica (oral information from Dr. F. E. V. Smith), and California, where Up-to-Date (referred to as British Queen) is susceptible [36, 48]. Blighted tubers are particularly prone to premature sprouting, as are those affected with the witches' broom or wilding virosis [43, 44, 44A].

It is remarkable how little is known of this very pronounced form of premature sprouting. It is generally held, on the authority of Klebs [49, p. 137], that tuber-dormancy does not set in until the last stages of growth, and this is held to account for the sprouting of half-grown tubers. The experimental basis [50, 49, 51] is very slight and rests almost entirely on plants grown in pots under glass, which are very prone to second growth and other drought-effects. The present author has failed to confirm Herfel's work [51] in this connexion. Klebs' conclusion is also opposed to experience, for immature tubers do not have a shorter resting-period than mature ones [37, 48].

It has been shown in the experimental portion of the present paper that premature sprouting is a consequence of water-loss from the tubers as a result of drought. The present problem therefore is to determine why the new growth takes the form of aerial shoots rather than stolons.

The destiny of sprouts emerging from tubers is alterable by external conditions, e.g. long days, high temperature, and abundant moisture cause stolons to grow upwards and become aerial shoots [52, 24, 48]. A short day following a long one has apparently the same effect [53], and a light dressing of naphthalene has been found at Glasnevin to cause the stolons to grow up to the light also.

It is probable that the presence of roots is necessary before aerial shoots can appear, for without roots the elongation of sprouts in light is impossible [54] and their growth in the soil is limited [40, 41], as already shown in the experimental portion of this paper, apparently because the new growth is dependent on the roots for its mineral supply [38]. The soil conditions which lead to copious root-production are probably similar to those governing the rooting of cuttings [49, 55], and consist principally of a moist soil which injects the intercellular spaces of the young developing shoot and leads to reactivation of the cambium and consequent root-production, and a high temperature [6, 48]. Etiolation or the prior presence of leaves is not a factor [55], because rooting of the sprouts begins in the absence of both.

Premature sprouting, in storage and consequent faulty germination after planting are delayed developments of the same phenomenon and arise from the same causes, seeing that they commonly follow drought years [46, 41, 56]. Furthermore, in mulching experiments, a straw cover was found to prevent not only prolongation but a tendency of the tubers to wilt at the stem-end in store and to sprout prematurely [31].

The present experimental work provides, so far as is known, the first experimental connexion between water-loss from the developing tubers and loss of dormancy. The explanation is in harmony with practical experience, for northern seed-potatoes are more dormant than southern ones, and those grown on sand are generally earlier than those grown on clay or bog. In warmer climates tubers from the summer crop have a 1–6 weeks' shorter rest-period than those maturing in autumn [57]. Under still hotter conditions, as in tropical Africa and the southern United States [29], dormancy is completely lost and the tubers vegetate at once when returned to the soil after digging the previous crop.

8. *Stem-end wilt and water-loss.* Visible wilting of the tubers is extremely rare in Ireland and has been observed only four times in the dry years 1933 to 1935, in President, Arran Pilot, and British Queen. It has not been reported from Scotland, but is apparently commoner in southern England. The first known record is by Appel [46], following the great drought of 1911, and similar records were made in 1921 [58, 59]. The condition is best known in the western United States, where tubers at harvest may show a withering of the stem-end 'as though part of the water had been withdrawn from that portion', sometimes accompanied by jelly-end rot [60]. The injury is attributed to drought and excessive transpiration, as a result of which the leaves draw on the tubers to eke out the water-supply, a probable consequence being the sprouting of half-grown tubers and other forms of second growth [36, 48]. In other cases, in the present work as well as elsewhere [31], tubers grown under hot and dry conditions may show no perceptible sign of softening

at digging, but they wilt rapidly in storage and sprout prematurely. It is practically certain that these also must have suffered a loss of water during the growing-period, but carbohydrates and nitrogen may also decline under hot, dry conditions [24, 3].

The changes which result in wilting, half-grown tubers have been found in the present work to include partial or complete disappearance of starch from the heel-end and an increase in the amount of reducing sugar (see [61] for method of estimation), an occurrence which is paralleled by wilting leaves [62]. There are other instances also in which water-loss leads to premature or forced growth of woody or bulbous plants [63], but the mechanism of the connexion is not entirely clear.

It is generally agreed that experimental shortening of the rest-period of potato tubers is correlated with an increase in oxygen-absorption and sugar-content. Thus the following treatments promote early sprouting, and all of them are accompanied by a rise in sugar-content and respiration: lengthened storage at or near 0° C. and subsequently at a higher temperature, peeling and wounding, treatment with various chemicals, and heating in water or in air. Loss of water from tubers stored in a room is also said to lead to heightened respiration at first, which drops on further water-loss and again rises when the shrunken tubers are put in water [64]. It is evident that water-loss from the growing tuber must operate along similar lines.

When unsprouted soft tubers are placed in moist soil, they begin at once to absorb water slowly but do so much more rapidly when sprouts and roots appear. This is clear from Text Figs. 2 and 4, and is opposed to the conclusion that most of the water is absorbed through the lenticels [51]. The swelling of soft tubers to more than their original size is well known [51, 65, 66], and is in keeping with the fact that the plane surface of cut sets becomes convex after planting.

9. *Glassy end and jelly-end rot* is a rarity in Ireland and has been found only in Arran Cairn and Arran Pilot, which are particularly susceptible, as is Golden Wonder in Scotland and Burbank in the United States. All these varieties have long tubers. The disease has been most fully described in Australia [67], where it is attributed to drought which injures the leaves to such an extent that they are not able to supply all the carbohydrate needed for new growth (i.e. second growth) when rain follows. Tuber-composition is affected by the disappearance of starch and an increase in reducing sugar in the glassy portion; but the Australian work makes no mention of water-loss. There may be no external symptoms, or the tubers may show stem-end rot.

Observations in Ireland show that glassy end follows drought and is associated with some or all of the following: second growth, stem-end wilting, and premature sprouting, and is usually followed by jelly-end rot (Fig. 2, Plate 14). The stem end shows a progressive soft rot, in advance of which the flesh is yellow and glassy and devoid of starch. The rot eats away a large part of the original tuber and then stops and is sloughed off, as though cut off by a knife (Fig. 3, Plate 14). No parasite capable of rotting normal tubers is present. In one case the specific gravity of the glassy portion of a tuber was 1·047, of the middle portion 1·100, and

of the terminal portion 1·134. The sequence of events in these cases is believed to be: water-loss due to drought, second growth mainly at the expense of the primary tuber, and rot of the evacuated stem-end. Apart from water-loss, however, tubers may lose carbohydrates and nitrogen under certain very hot conditions, and may even be completely re-absorbed [24].

The extensive literature connecting species of *Fusarium* with the American jelly-end rot (Fig. 7, Plate 15) cannot be reviewed. The same association has been noted in Ireland in the last three years and a species of *Fusarium* which is at present under study, amongst other fungi, has been isolated, but all failed completely to produce rot in normal tubers.

10. *Drought and heat necrosis.* This disease occurs under very hot conditions and is marked by the death of the vascular ring and surrounding parenchyma, which turn golden yellow and later brown. It is most marked in the outer phloem and cortex, especially at the rose- and heel-ends, which distinguishes it from net necrosis which also occurs in the pith. In another form of the disease, groups of yellow or brown dead cells, varying from specks up to one-half inch in diameter, develop in any part of the flesh, sometimes in storage [34]. The diseases occur in hot, dry, light soils, particularly when the plants are dying from drought and the crop is left undug, but they have not been reproduced experimentally and their relationship to other forms of tuber-necrosis due to overheating [68], calcium deficiency [12], and viruses [69, 70, 1], remains to be determined.

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Summary

After the dry summer of 1933 a few President tubers were found at digging time to be soft, due to loss of water. These tubers sprouted at once in October when placed in moist sand, but hard tubers from the same plot did not do so.

Many tubers from this plot, which were not noticeably soft when dug, shrivelled and sprouted prematurely during storage in autumn.

The absorption of water by soft tubers began at all temperatures from 5°–20° C. as soon as they were placed in moist sand, and continued at a slow rate until, at favourable temperatures, sprouts and roots appeared. Sprouting increased the rate greatly, and rooting still more so.

As a consequence the tubers became firm again, having absorbed about 30 per cent. or more of their original weight of water. Tubers at low temperatures which did not sprout were still soft after 8 weeks in moist sand, showing that most of the water is absorbed through the sprouts and roots.

Evidence is presented that the yield of crops dug during severe drought may be reduced by water-loss from the tubers.

Various effects of drought on potato tubers are discussed and 10 types are defined and described. These are cracking, hollow heart, prolongation, gemmation, chain-tuberization, independent tuber-formation, premature sprouting, stem-end wilt, glassy end, and drought and heat necrosis.

The occurrence of these various types in different countries and on different varieties is described, and the conditions favouring them are discussed. It is shown that a number occur in association, such as cracking and hollow heart, glassiness, jelly-end rot and prolongation, softening and premature sprouting.

The production of leafy shoots from half-grown tubers is connected with free formation of roots in a moist soil, and the loss of dormancy by soft tubers with starch hydrolysis following partial desiccation.

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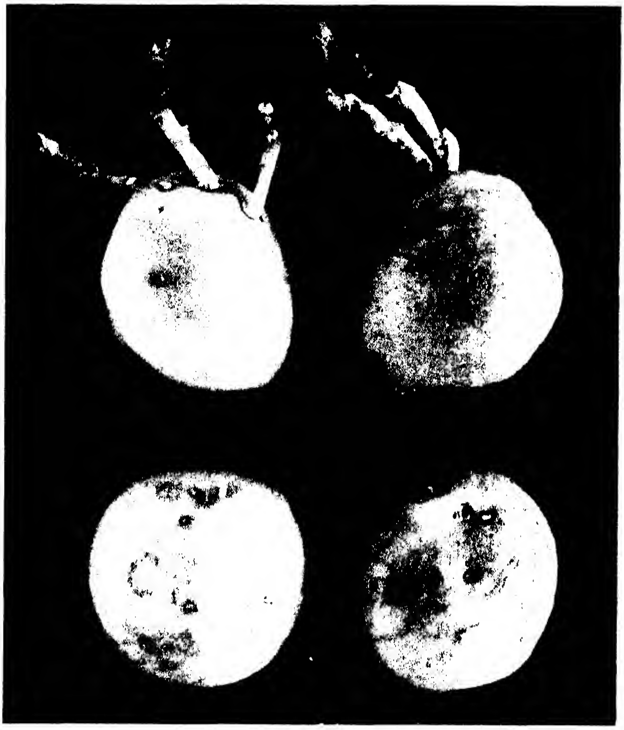

FIG. 1

FIG. 2

FIG. 3

(1) *Above.* Two soft tubers which sprouted at once after digging, showing complete absence of dormancy. *Below.* Two normal tubers from same plot. See Expt. 1 (Photo. 5.12.33). (2) Jelly-end rot (*below*) and prolongation in Arran Cairn. Note waist, smoother skin of new growth, and blackening at tip due to rubbing. (3) Same, showing disappearance of large part of original tuber, nodular second growth showing superficial injury and cracking (Photo. Feb. 1935).

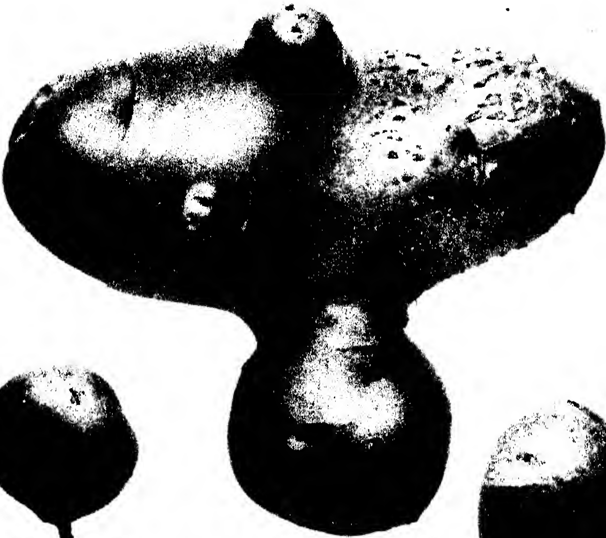

FIG. 4

FIG 5

FIG. 6

FIG. 7

FIG. 8

FIG. 9

(4) Second growth by gemmation in Majestic showing various stages of development. (5) Chain-tuberization in President. (6) Prolongation in President. (7) Extreme case of prolongation in Arran Victory, the small projection representing the original tuber. (8) Jelly-end rot in Burbank. (9) Cracking experimentally produced in dormant tuber in moist sand at 0°–2° C.

SOME ASPECTS OF TOBACCO CULTURE IN CENTRAL AFRICA

C. W. B. ARNOLD

TOBACCO is a weed only in the sense that it can be grown anywhere in the world. The production of tobacco with a value in the world's markets, however, has regional limits owing to the profound effect on the crop of such factors as soil, rainfall, sunshine, and humidity. Even with suitable soil and climate it may still fail commercially owing to the attacks of soil pests: nematodes, cutworms, stem-borers, leaf-eating caterpillars, beetles, grasshoppers, aphids. It is susceptible to mosaic and other virus diseases as well as to leaf-spotting fungi and bacteria, which reduce the yield and quality of the product.

On the economic side, the cost of agricultural labour is a very important factor in tobacco culture, as each leaf has to be handled many times from when it is taken from the plant until it is packed in bale or hogshead for shipment to the manufacturer. Only cheap agricultural labour can produce tobacco at a competitive price.

Varieties.—Few agricultural crops show such specialization as is found with tobacco; new varieties are being bred and improvements are continually being made in the older strains to make them more suitable for the production of particular types of cured leaf. The large distinction among the varieties is based on their suitability for curing by one or other of the standard methods and yield of leaf for a specific purpose: (1) fire-cured; (2) sun-cured; (3) air-cured—Burley; (4) air-cured—cigar-leaf; (5) flue-cured—pipe-grades; (6) flue-cured—cigarette-leaf.

Numerous varieties have been developed which are specially adapted for yielding a high-quality product of one or other of these main classes. There is no 'utility variety' which, by merely changing the method of curing, could give a cigar-leaf, pipe-leaf, or cigarette-leaf of high quality.

Presuming now that flue-cured pipe tobacco is aimed at, the choice of variety must still be made, and experimental work becomes all important. Experience shows that a successful variety in one region may fail in another owing to obscure differences of soil or climate. The process of improvement of varieties has doubtless introduced weakness or sensitiveness, and thereby limited the region in which a particular variety can be grown successfully. Actual trials only will decide the most profitable one for a given area, and every plantation should have trial plots on which selections from the farm or another variety can be compared with the main crop.

Variety trials.—Exact experimental work with tobacco presents many difficulties. The value of a field of tobacco is not seed-weight, green-weight, or even cured-weight, but sold weight of cured leaf per acre. Nevertheless, in any variety trial, the appearance of the plants in the field, their vigour as judged by the number of leaves they will carry, resistance to disease, ability to withstand excessive rain or drought, and rate of ripening, should be observed and recorded. No variety can be a commercial

success which fails the test of its field characters. Errors are more likely to occur during the operations of harvesting, curing, bulking, and grading. Close supervision is essential from the time the ripe leaf is harvested until it is sold, and few planters are able to carry this through and furnish reliable reports. This is the work for the experiment station.

Variety trials on most farms might well be limited to obtaining field observations on one or two varieties, using plots of ¼-acre each. A single variety could be carried through the curing and grading on the farm, provided a minimum of 5 acres is planted. This area would enable one barn to be filled completely with the variety under trial.

If smaller plots were used, the amount of leaf harvested at one picking would be too small to fill a barn, and attempts to cure mixed barns, i.e. those filled with leaves of two different varieties, invariably fail, as no two varieties cure exactly alike. One has to be sacrificed in favour of the other, and the smaller lots from the variety under test always suffer, with the result that it is condemned as showing 'bad curing qualities'. Even if this difficulty is avoided, the amounts of leaf produced are too small to bulk down separately, and become lost or mislaid. Should they be duly graded the quantities of the grades will be small and difficult to value.

A variety cannot be condemned or approved outright after one season's trial. All the circumstances of the season must be given due consideration, and a promising variety should be tried out for three successive seasons to appreciate its value under varying seasonal conditions. It is the value per acre in bad seasons that is the critical test, as a mediocre variety will yield well under good conditions.

Tobacco soils.—A soil can only be considered as suitable for the culture of tobacco on a commercial scale if it yields a product which is acceptable to the smoking public. As with all luxury products, the taste of the consumer is paramount. Experience shows that rich soils, i.e. those rich in organic matter and nitrogen, are not as a rule 'tobacco soils', for although growth will be vigorous and yields may be heavy, the cured leaf is usually thin and trashy, and tobacco manufactured from it smokes rank and objectionable.

Each of the types mentioned above has its appropriate soil, and the ideal for producing bright cigarette-leaf is a light sand, poor in humus and nitrogen, rich in phosphoric acid and potash. The soil should be as light as possible in colour and with only meagre iron-content. Such an ideal soil is virtually non-existent, for with this richness in mineral constituents it would naturally have encouraged the growth of vegetation during the ages and have been converted into a rich soil, i.e. rich in organic matter and nitrogen from accumulated plant-residues.

The soils which approximate to the ideal evidently suffer from some disability, but deficiencies can always be remedied by the addition of appropriate amounts of plant-foods, whilst excesses cannot easily be got rid of. They must be poor in organic matter and nitrogen, and, indeed, some are remarkably poor and are little more than light-coloured sands, capable of holding a stick upright but with little natural fertility.

If the colour of the cured leaf is of less importance, as in flue-cured

pipe-grades, air-cured leaf, dark-fired leaf, larger amounts of nitrogen and organic matter are permissible, and the heavier grades may be produced on relatively fertile soils.

The physical character of the soils is rather less restricted. Their essential feature is that they must be of open texture and naturally free-draining. The tobacco plant will not tolerate a water-logged soil but will promptly die, possibly from deficiency of aeration, and certainly as a result of injury from fungi or bacteria that are encouraged by the water-logged condition. The plants succumb quickly and root-disease cannot always be proved. All forms of subsoil pan are inimical.

In cases where good tobacco has been seen on loams, there was always a natural looseness of the soil *in situ*. Virgin land almost invariably gives good tobacco for a year owing to its excellent texture, due to the presence of large quantities of undecomposed plant-residues, not yet humus. When these have been converted to humus, the amounts of the ultimate soil particles, sand, silt, clay, humus, decide the soil texture. One finds it almost essential to judge the soil *in situ* in order to decide its suitability for tobacco.

The tobacco plant.—As grown for commercial purposes the tobacco plant has an unnatural life. It is sown in a seed-bed of rich or heavily manured soil which has been sterilized by heat and is carefully shaded and watered. After 6 to 8 weeks it is planted out in a field which has been carefully prepared and manured. For 2 or 3 weeks growth is slow, but later on it becomes very rapid, and the flower-bud appears 7 or 8 weeks after transplanting. At this stage, the treatment of the plant depends on the type of tobacco which is to be produced. With bright flue-cured varieties, the flower-head is allowed to expand about half-way, and at this stage the natural development of the plant ceases as the flower-head and certain leaves at the top and bottom are removed. In its endeavour to produce seed it pushes out suckers in the axils of the leaves. These are removed, and a second crop of suckers appears, which receives the same treatment. This induces an unnatural expansion and thickening in the remaining leaves, which gradually become paler in colour and brittle. When this condition is sufficiently developed, they are harvested one or two at a time, starting with the lowest leaf, tied to bamboos, and carried to the barn for curing.

One can regard the life of the tobacco plant as comprising the following stages:

Stage 1. The nursery period lasting 6 to 8 weeks and terminating with transplanting.

Stage 2. The period of slow growth following transplanting lasting 2 or 3 weeks. The young plants are recovering from the shock and are becoming accustomed to full sunlight, heat, a change of soil, and generally the hardships of field life.

Stage 3. The period of vigorous growth lasting 4 to 5 weeks and closing with the topping.

Stage 4. The ripening period lasting 4 to 6 weeks.

In the first three stages there is a considerable intake of plant-foods, and elaboration takes place in a natural manner.

The ripening period is abnormal, as seed-production is frustrated and

a sort of fattening process is induced. All plant-food taken in during this period is forced into the limited number of leaves, and any considerable intake of nitrogen is attended by disastrous results. Its obvious effect is to cause the rich green colour to stay obstinately in the leaf, or, as the planter describes it, the leaf 'refuses to ripen'. If such unripe leaf were harvested it would cure badly and produce either muddy, blotchy colours, or dry out green and yield a low grade or even an unsaleable product. The ideal condition would be for the intake of nitrogen to cease with topping. The tobacco plant, however, is a gross feeder, and if nitrogenous plant-food is available it will continue to absorb it throughout its life. Unfavourable weather conditions at this stage result in outbreaks of leaf-diseases, which are more severe on rich land and on land which has received heavy dressings of nitrogenous manure.

When this point is grasped, the planter will understand the reason for some of his failures. It will explain why a rich soil is unsuitable for bright tobacco, why the composition of the manurial mixture, and especially the forms of nitrogen in it, are important, and the cause of the condition called 'second growth'. Rainfall is beyond control, but it is for the planter to exercise great care in the selection of his tobacco fields, in manuring and cultivation.

Manuring

The whole subject cannot be dealt with here. The principles, however, can be inferred from the foregoing remarks on the soil and the plant. Different manuring-systems must be adopted according to the type of tobacco under cultivation and according to the soil.

Some of the soils used for the production of dark-fired tobacco in the Lilongwe district of Nyasaland have produced crops of excellent tobacco for a few seasons without any fertilizer. Climatic conditions there usually favour the cessation of nitrogen-absorption after topping, with the result that perfect ripening takes place. At the first sign of exhaustion, the land is abandoned; soil amelioration and manuring are left for a later generation.

The soils used for producing heavy, flue-cured tobacco (pipe-grades) in Nyasaland are often rich in nitrogen and organic matter and have a fair mineral content. Newly opened land, where the nitrogen is still largely locked up in plant-residues, gives crops of good quality, and a small application of quick-acting nitrogen often improves the yield without depressing the quality. The difficulty on the older soils is to avoid big, leafy growth, which ripens slowly and colours very slowly in the barn, producing tobacco which is dark in colour and of inferior texture. No nitrogen is applied in the second or third year, but double superphosphate and potassic superphosphate are used according to the known deficiencies of the soil. It seems doubtful whether this manuring is really effective after the third season, and a change of crop is necessary.

Bright tobacco soils are more common in Southern Rhodesia. They have the desirable low organic matter and nitrogen, and are usually deficient in one or more minerals. They would be classed as sands or light sandy loams. Without additional nitrogen, growth is poor and

small. Manuring is essential and in most cases complete fertilizers are required. In this country of large farms, the custom appears to be to abandon fields after two crops have been taken, and few planters have seriously tackled the problem of how to maintain or regenerate the fertility of their old fields.

No standard manurial formulae can be laid down for flue-cured tobacco in Central Africa similar to the 8–3–3 or 8–3–5 (P_2O_5–NH_3–K_2O) which are in general use in the United States. The soils are too varied in composition, and whilst some require little nitrogen, others require 25 to 30 lb. per acre. Artificial manures are costly, and no farmer can afford to put out manure which yields no return. The maximum effective applications of phosphoric acid and potash are about 30 lb. per acre, larger amounts showing no additional benefit.

The form of nitrogen in a manurial formula is of the greatest importance, and must be considered in conjunction with the soil nitrogen, the rainfall of the district of application, and the nature of the preceding crop. Organic nitrogen, such as is derived from fish, blood, meat-meal, and oil-seed residues, cannot be leached out by rain, and yields a continuous supply of nitrogen throughout the season. Soil nitrogen derived from plant-residues and green manures is of similar availability. These forms are beneficial in moderate amount and especially in wet seasons. When present in excess they are injurious by promoting growth when it is desired that the tobacco should ripen, i.e. after topping. Inorganic nitrogen derived from nitrates is entirely available from the time of application. The soil cannot hold it and any that is not taken up by the plant is leached out by rain. Should continuous rain be experienced shortly after application, much of the nitrate will have gone before the plants can take it up. Nitrates can be regarded as very safe in the respect that they are likely to be exhausted by the end of the third stage. Inorganic nitrogen in the form of ammonia (sulphate of ammonia, diammonium phosphate) is retained by soil to a great extent and cannot easily be leached out. Under the influence of soil bacteria it is progressively changed into nitrate, which more or less suits the demands of the growing plants. Ammonia is not so safe as nitrate, as climatic conditions may occur which delay its action unduly.

The proportions of these forms of nitrogen should suit the requirements of the plant in the average season, and they must be determined by careful trials over a succession of seasons. If they were ideal in a dry season, they would be quite unsuitable in a wet year. The proportions recommended by a Conference of Tobacco Experts in the United States are of great interest in showing the adjustment of components of various degrees of availability:

'*Ammonia.*—One-half of the ammonia should be derived from high-grade organic materials of plant or animal origin, such as cottonseed meal, fish-scrap, and high-grade tankage. At least one-fourth of the total ammonia is to be supplied by nitrate of soda. The remainder should be derived from such materials as urea and/or standard inorganic sources of nitrogen. For the heavy Cecil soils of Virginia three-fourths of the ammonia may be derived from the above-designated mineral sources and one-fourth from the organic sources of plant or animal origin.'

Note the recommendation that the slow-acting organic nitrogen should be reduced for tobacco growing on richer soils.

The phosphoric acid in the mixture should be derived for preference from ordinary or low-grade superphosphate. The potash should consist of sulphate and muriate in equal proportions.

Method of application.—One has listened to much argument on this topic and wondered how little the feeding of the plant has been considered even by those who set out half a million or more tobacco plants every season. If three well-grown plants were dug out after harvest in a dry season, and also after a wet season, and examined, there could be little difference of opinion in the matter. The thick cluster of feeding rootlets will be close to the surface in the wet season and somewhat deeper in the dry season. The spread of the roots indicates the feeding-range. Fertilizer should be so distributed that, whether the season is dry or wet, some of it will be accessible. Occasionally when pulling out a stalk after harvest, one or two grey cartridge-like blocks of fertilizer have been dislodged, reminding one of the buried talents which yielded no interest. The method of application was obviously wrong.

Tobacco fertilizer should be well mixed with the soil and never placed in a single spot. It should be covered to prevent it being carried away by heavy showers. Phosphoric acid and potash are very soon fixed by the soil and tend to remain where they have been placed, i.e. they have little or no mobility. Nitrogen in the form of nitrate is very mobile and tends on the whole to move downwards.

Side dressings.—The advisability of applying additional fertilizers after the plants have been established for a week or more has often been raised. Such dressings are variously described as side-, top-, or after-dressings. Their use will depend on local circumstances, the soil, and on the loss which has meantime occurred in consequence of leaching rains. When transplanted, the leaves are very small and quite inadequate to protect the surrounding ground from severe washing. The proportion of nitrogen lost when, say, 10 in. of rain have fallen will naturally depend on the composition of the fertilizer and on the soil-type, and careful consideration should always be given before applying after-dressings. The planter must realize that he is speculating on the weather of the remainder of the season. A very rainy period is often succeeded by two or three weeks of drought, and any fertilizer supplied at the beginning of the drought period is not likely to act until the drought breaks, and this may cause the growing-stage to be prolonged into the ripening-period with the consequences mentioned before—'second growth'. The safest form of nitrogen for after-dressings is undoubtedly nitrates. The question has been raised regarding the efficacy of complete fertilizer as after-dressing, and instances have been quoted of benefits derived from it. In view of the lack of mobility of phosphoric acid and potash it is unlikely that these constituents have much effect in the subsequent improvement of the crop, as they can never be worked down into the soil without grave risk of injury to the roots. The benefits observed from such after-dressings are probably due entirely to their nitrogen-content, whilst the phosphoric acid and potash are wasted. With severe eelworm-injury, however, the

complete fertilizer will be beneficial, as all the feeding-roots will lie near the surface.

Pests and Diseases

This also is a very wide subject and the following remarks are not comprehensive.

Eelworm.—The most pernicious soil pest is the root-knot eelworm (*Heterodera marioni*). When once established in the fields it virtually means the end of successful tobacco culture, and the greatest precautions should be taken to avoid introducing or extending this pest. Research on the eradication of eelworm has been extensively pursued, but no method has been found which is really practicable in the field. The precautions to be taken are:

1. The nursery-beds should be well burnt, whether these beds are on virgin land or have been previously used for nurseries.

2. After the first pulling from the seed-bed, any later plants should be examined and rejected if root-knot is observed. No chemical treatment of the plants will destroy the pest when it is once established in the roots, without the destruction of the plant itself.

3. An ample 'yardage' of nurseries should be sown in succession to allow for some to be rejected, and for the purpose of supplying blanks in the field. It is very risky to draw such supplies from old nurseries, or to obtain them from neighbouring farms, as they may be old plants and probably infected by the eelworm.

4. As soon as all necessary plants have been drawn from the nursery, the remainder should be pulled out and destroyed, and the nursery land planted up immediately with some immune crop.

5. If infected plants are discovered growing in the field in spite of the planter's vigilance, he must realize that unless special attention is given, his crop may become a complete failure, for eelworm destroys the ability of the roots to carry out their function. The only hope in such a case is to assist the plants to develop new roots, and to keep this development a little ahead of the pest. Earth should be drawn up round the stem, and the operation repeated weekly throughout the growth of the plant. Such soil will have the greater benefit if enriched with complete fertilizer. The signs of eelworm-attack are fairly well known, and in case of doubt a stalk should be pulled up here and there and the roots examined.

6. After harvest all stalks should be pulled out as cleanly as possible, dried in the sun, and burnt.

Cutworm.—The larvae of the sundry insects which have developed in the soil become active about the time when the tobacco is transplanted, and severe attacks have occasionally been traced to the preceding crop. If a green manure has been ploughed in rather late in the previous season, so that rotting down has been delayed, it is probable that severe cutworm injury will occur in the succeeding tobacco crop.

Leaf-eating caterpillars.—Should any outbreak occur in the nurseries one concludes that they have not been adequately covered by cheese-cloth, which would have excluded the moths responsible for these pests. Poison sprays may have to be resorted to in the nursery, but on no account should such materials be used in the field. Any leaves

which bear suspicious stains suggesting spray residues may result in the rejection of the cured leaf by the buyer. Hand-picking of caterpillars, grasshoppers, &c., is necessary. Generally speaking, the severity of insect-injury depends on climatic conditions.

Bacterial and fungoid diseases.—Provision against these must begin in the nursery, and the plants should be sprayed at intervals of 5–7 days with Bordeaux mixture. At the time of transplanting, all spotted leaves should be removed and destroyed, as these are potential sources of infection. Any mild outbreak in the field should be dealt with in the same manner, as it is far easier to check disease at an early stage than when it has reached serious proportions. Climatic conditions have a great influence on disease-outbreaks, and there seems little doubt that there are conditions and phases of susceptibility to disease in the plant itself. Periods of high humidity and misty weather favour their spread more than actual rains, and it is thought that mist in particular assists disease-spores to spread over the leaf, and gives them ample opportunity to germinate, whereas rain would probably wash them off. Plants which have received heavy nitrogenous manuring are particularly susceptible, possibly because of the preponderance of large, watery cells with soft walls. At the ripening-stage, the leaf is very susceptible to disease. Spots often appear in the early stages of curing, even when apparently clean leaf was put in the barn. Such spotting has been traced to the same organisms which produce leaf-spot in the field, and the curing barn has merely acted like an incubator in developing the spores. No method is known of preventing the development of 'barn-spot', as the organism is more difficult to kill than the leaf itself. The early stages of curing must be carried out below a certain temperature, and this is far below the lethal temperature of the disease-spores.

It has been observed that, provided there is ample sunshine between showers, a crop will remain clean in spite of moderately heavy rainfall. The crop may become badly diseased under smaller rainfall if sunshine is deficient, as in misty weather. One may say that provided the leaf dries between showers, disease-organisms are at a disadvantage.

Seed should always be disinfected before sowing to get rid of any spores that may be resting on the outer coat.

Virus diseases.—Diseases of the mosaic type cannot be checked in an infected plant, and due care should be taken to avoid their introduction and spread. Ordinary mosaic is highly infectious, and may be carried to every plant along a row and, indeed, to every plant in the field from the hands of the labourers. A rule should be made that an infected plant must never be touched by the ordinary labourer. Leaf-crinkle was proved by Dr. Storey to be a virus disease transmitted by a small, white fly. This disease cannot be transmitted from the hands of workmen. Its control has been effected by the destruction of the host plants on which it subsisted from one season to the next. The commonest source of infection was found to be old tobacco fields and nurseries which through negligence had not been uprooted after the previous crop.

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FORAGE-CROP IMPROVEMENT IN WESTERN CANADA FOR DRY-LAND AGRICULTURE

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In a previous article [1] dealing with forage crops in western Canada, an attempt was made to outline the present status of forage-crop production under dry-land conditions, and the methods and practices which have been most successful in the different soil-climatic zones in that part of the Dominion. If this is read in conjunction with the present paper it will provide a background and perspective for an understanding of the objectives in such efforts as are being made to obtain better strains of grasses and legumes for the type of agriculture peculiar to the country. Whatever interest there may be for readers in other countries in the work which has been undertaken on crop-improvement in western Canada, and in the results accruing therefrom, this is sure to be increased if there is at the same time some appreciation of the precise nature of the natural environment, especially of the large part played by climatic factors in the adaptation and utilization of the crop plants.

Ability to persist without injury under exceptionally dry conditions and severe winter temperatures, which occur periodically, is the first essential of a satisfactory species or variety. This is so true of western Canada that crop-improvement becomes as much a study of plant-adaptation as of plant-breeding. In the first place, one has to work with highly adapted species, and sometimes, after years of intensive breeding and selection, one's best reward is a new appreciation of the essential agronomic value of a particular species or variety for this or that soil-climatic zone, or for a special purpose. This has been the case, to a greater or less extent, with all of the major grasses and legumes. An effort to improve these crops has gone hand in hand with an intensive study of their growth-characteristics, with the result that marked progress has been made towards zoning the country with respect to the adaptation of species. This preliminary, but nevertheless difficult, phase in the process of crop-improvement is of great importance in a country so large and exacting as is western Canada, and it is this feature of the crop-improvement work which certainly must rank with any progress in plant-breeding that has been achieved.

In the article previously referred to, it was pointed out that climatic conditions in western Canada limit the choice of forage crops for the most part to three grasses and two legumes. These are brome-grass, *Bromus inermis*; slender wheat-grass, *Agropyron tenerum*; crested wheat-grass, *Agropyron cristatum*; alfalfa, *Medicago*; and sweet clover, *Melilotus*. Other forage crops, grown to a small extent in limited areas, include timothy, red clover, and maize, and to these must be added also the cereals, which are grown most extensively. The present discussion of crop-improvement deals only with the two legumes and three grasses referred to above.

Alfalfa.—For many years western Canada has produced almost all the alfalfa seed it needs. The seed-stock came originally from Minnesota, having been introduced from Europe by a farmer named Grimm. It was subjected to natural selection on his own place for a period of fifty years, and seed from this source became known as the Grimm variety. For many years almost the only source of Canadian-grown seed was to be found in a certain district of southern Alberta, where the Grimm variety was produced on irrigated land.

Twenty-five years ago agronomists recognized that one day alfalfa would become an important crop, but there was some doubt of its winter-hardiness, and its range of adaptation was not well understood. It was generally conceded, however, that this crop had greater potentialities than any other perennial legume for an area like western Canada, with its rigorous winter climate and limited precipitation, but where the soil was generally favourable for its culture. For these reasons an extensive programme of improvement was undertaken by the Saskatchewan Agricultural College long before alfalfa began to be grown by farmers to any appreciable extent.

The first step was to bring in from many sources some twenty-five of the hardiest varieties or regional strains. The less adapted of these were soon eliminated by winter-killing, and eventually 1,300 selections were obtained representing single plants which had survived severe winter conditions. These were studied in clonally-propagated rows, selfed progenies, and progenies from open-fertilized seed. After several years of work, fourteen of the best strains were retained, and these were subjected to four generations of inbreeding with selection within the self-fertilized lines. The results of this study from the standpoint of yield and seed-production have been discussed elsewhere [2, 3, 4].

The results of selfed-line breeding with alfalfa in these experiments was not impressive as a practical method of improvement. Vigour of growth, as measured by yield of herbage, was reduced on the average by 46 per cent. Reduction in yield of seed was still more pronounced, amounting on the average to 78 per cent. The accompanying table gives the distribution of 61 fourth-generation selfed lines of alfalfa according to seed-yields expressed in per cent. of the mean yield of 18 check plots of the standard Grimm variety:

Seed-yield Classes

Median values	5	15	25	35	45	55	65	75	85	95
No. of selfed lines	20	18	8	6	2	1	2	2	2	0

Although it was found that inbreeding of alfalfa resulted usually in pronounced loss of vigour, it should not be concluded that this will always be so. Although the experiment occupied approximately one to two acres of land per year, the number of selfed lines must be regarded as relatively few, and all of them, except one, originated with the Grimm variety. Tysdal [5], on the other hand, working with selections of Turkestan alfalfa, obtained some selfed lines which were as productive as the parent sort. It seems probable that the difference between the

results in these two instances was due to a fundamental dissimilarity in the breeding-material.

Considering the physical difficulty of handling more than a few score selfed lines of alfalfa, the reduction in vigour which usually accompanies inbreeding, and the pronounced effects of inbreeding on seed-production, the method of 'strain building' described by Jenkins [6] would seem to have wider application. This admits of various methods of selecting parent plants and different systems of mating, and it aims to maintain the maximum vigour, as far as this is consistent with progress towards the desired result. The important thing, of course, is a satisfactory method of evaluating the breeding-potentialities of the parent plants. The method which seems to be most promising for this purpose is to determine the 'inherent' and 'combining' values of the parents by comparing their progenies produced from 'selfed' and 'out-crossed' seed, respectively.

Hand-in-hand with the breeding-programme, an effort was made during twenty years to improve the local adaptation of the original Grimm variety by a systematic process of mass selection. This resulted in a strain of Grimm alfalfa, designated 'Sask. 451', which is distinctly more winter-hardy but not more productive. The only change in appearance was a pronounced 'lightening' in flower colour, the mass effect being very noticeable. Seed of this mass-selected strain has been distributed quite widely and has proved very satisfactory; but as a variety it could not compete successfully with the original Grimm variety for the reason that seed of the latter was produced in such relatively larger amounts on irrigated land in southern Alberta that it dominated the seed-supply.

During the last ten years, however, the problem of winter-hardiness has become less urgent. There may be several reasons for this. In the first place the Alberta-grown Grimm alfalfa seed also has been subjected to rigorous climatic conditions which, through natural selection, may have increased its winter-hardiness; secondly, the area which is now recognized as best suited to the alfalfa crop has normally a good snow cover, and conditions generally are favourable for the winter survival of perennials; and lastly, there is a better understanding of the factors making for successful alfalfa culture. To the writer, this last consideration seems to be the most important. Generally speaking, alfalfa seed grown in western Canada now appears to be sufficiently hardy for all practical purposes.

As previously indicated, the irrigated land in the neighbourhood of Brooks, Alberta, produced the bulk of alfalfa seed used in western Canada for many years. Manitoba and Saskatchewan were thought not to have favourable conditions for seed-production. During the last few years this situation has radically changed until now Saskatchewan produces more alfalfa seed than Alberta, and Manitoba produces considerable quantities. Nearly all of the seed is of the Grimm variety. It is of interest also that, contrary to expectations, this development has occurred in the northern park-belt rather than in the southern plains, and recent observations would indicate that the leached grey soil in Zone 4 is likely to give consistently larger crops of alfalfa seed than the black soils of the parkland in Zone 3 (see sketch-map of major soil zones [1]).

The problem of improving alfalfa from a seed-production standpoint has received considerable attention. If alfalfa could be made to produce seed more consistently, the cost of seed might thereby be reduced—an important consideration—and the growing of seed placed on a profitable basis. Stabilization of seed-supply of an adapted variety would be an effective means of promoting a wider use of the crop.

The only tangible result of the extensive alfalfa-breeding programme outlined above is a strain of Grimm alfalfa designated 'Sask. 666'. This was released some years ago, and reports of its performance have been quite favourable. Like a number of other strains of variegated alfalfa, such as Baltic Cossack and Sask. 451, it has not been sufficiently superior or distinctive as compared with Canadian-grown Grimm to stimulate seed-production as a separate variety to a point where it has become available to the seed trade in quantity. The strain Sask. 666, originating with a single plant out of the Grimm variety, was selected originally as a consistently high seed-producer. In the process of seed-multiplication this characteristic was lost to some extent, presumably as a result of inbreeding resulting from self-pollination. Subsequent work has indicated that the high seed-production exhibited by the original plants was probably due to automatic tripping of the flowers. However, it did not reproduce this characteristic to the same extent under isolation.

Following this lead, an attempt is now being made to develop seed-production by a method which appears quite promising. Eight unrelated mother plants of the Grimm variety have been selected which produce seed abundantly and consistently by automatic tripping of the flowers. These have been synthesized into a single strain by crossing, the object being to concentrate the autogamous character and maintain maximum vigour. Progress reports of this study have appeared in three publications [4, 7, 8].

We now think that the Grimm variety of alfalfa cannot be further improved for use in western Canada at the present time, except with respect to seed-production. There is need, however, for a one-cut alfalfa and for types that are better adapted for pastures. These objectives are most likely to be attained through new introductions, such as 'Ladak', which is outyielding the Grimm variety at the first 'cut', and by selections and hybrids of *Medicago falcata*, which are low-growing and self-propagating by means of root-stalks.

Sweet Clover.—The importance of sweet clover as a hay, pasture, and soil-improvement crop in western Canada is ample justification for the considerable effort which has been made to improve it. The first extensive introduction of sweet clovers was made in 1916. Among these was a sample of seed from Prof. N. E. Hanson, of the South Dakota Agricultural College, who had obtained it in northern Siberia on one of his trips of exploration for the United States government. This proved to be a white-flowered, semi-dwarf, early maturing, five-stemmed uniform strain of exceptional winter-hardiness. It was subsequently increased at Saskatoon, and released to farmers under the name 'Arctic'. Since that time Arctic has been the best all-round variety of sweet clover in western Canada. With a rapid increase in sweet-clover acreage, many carloads

of common white-blossom sweet clover seed were brought in annually from eastern Canada and the United States, so that the Arctic variety now occupies only a portion of the acreage, making it more and more difficult to produce seed which could be certified as true to variety.

Many species, varieties, and strains of sweet clover have been studied at Saskatoon since 1920. The majority of these are coarser, taller, and less satisfactory than the Arctic variety. White-flowered sweet clover is grown much more extensively than the yellow-flowered sorts, the chief objection to the latter being their tendency to volunteer from shattered seed, the yellow flowers producing the appearance of mustard in subsequent crops of cereals. This is considered objectionable. Several distinct strains of yellow sweet clover have been developed but none of them has been established commercially.

For a concise outline of the objectives and methods used for improving sweet clover at the Dominion Forage Crops Laboratory, Saskatoon, Sask., the reader is referred to a recent article by Stevenson [9]. This paper also describes briefly the varieties that have originated as a result of this work, and includes a fairly complete list of literature references. A few comments on this work, therefore, is all that is needed.

The dwarf strains of white-blossom sweet clover, represented by the variety 'Alpha', are characterized chiefly by their numerous fine, short, leafy stems, which originate at the crown. The value of the shorter and finer herbage from the standpoint of hay-quality and ease of handling is best appreciated in parts of the black-soil zone where common sweet clover grows so tall and coarse that it is harvested and cured with difficulty. In the semi-arid plains of the West, on the other hand, the dwarf types tend to be too short in dry years. Here there is need for taller varieties, but similar to Alpha in fineness of stem. Such varieties are in sight as a result of crosses between the dwarf and tall-growing types. Some of these plants in the third hybrid generation are almost twice the size of the dwarf plants and possess the fine-stemmed, leafy habit of growth.

The Alpha variety has been shown to contain only about one-half as much coumarin as that of common sweet clover. It is distinctly less bitter to the taste, and therefore more palatable. Rightly or wrongly, sweet clover has long been criticized for its bitter taste, and progress in the development of strains that are free, or relatively free, from coumarin is regarded as a step in the right direction. Stevenson and Clayton [10] have recently discussed the results of their investigations during the last two years on coumarin in sweet clover, especially in relation to selection and breeding.

Other studies with sweet clover that may be mentioned concern pollination and fertilization, natural crossing, abnormal seed-development, inter-specific and inter-generic crossing, seed-mottling, inheritance of flower-colour, and inheritance of the dwarf branching habit of growth.

Awnless Brome-grass.—Awnless brome possesses most of the qualities which should characterize a thoroughly satisfactory grass for hay and pasture in the greater part of western Canada. It is highly adapted to the parkland soils and adjacent plains, but it requires more moisture than is sometimes available in the semi-arid sections.

The strongly spreading underground stems of brome-grass make it objectionable to many grain farmers, especially those on black 'parkland' soils and heavy clay soils. The crop becomes sod-bound within one or two seasons after the year of seeding, and this results in greatly reduced productivity. When the land is ploughed in preparation for a crop of cereals, the sod does not easily disintegrate, and the grass tends to re-establish itself in the soil by means of the stolons. In this behaviour the brome resembles couch grass (*Agropyron repens*), but in most parts of western Canada it is not so difficult to eradicate as the latter, and in fact does not present a serious problem when proper methods are followed.

During the last twelve years a sustained effort has been made to develop strains of brome-grass that would be characterized by a non-spreading habit of growth. Starting with a nursery of selected plants, the inbreeding method was adopted. Selfed seed is rather difficult to obtain, but a technique was found which proved successful under relatively dry atmospheric conditions [11]. Approximately 100 selfed lines were grown each year.

After four generations of inbreeding there was marked reduction in vigour of growth in most of the lines, but continuous selection towards a non-spreading type proved effective. Several strictly non-spreading lines were obtained, but these have been discarded in favour of lines with restricted spreading-habit. One of these gives much promise of being a very desirable sort, and the seed is being multiplied.

The non-spreading types of brome-grass are characterized by short underground stems, which emerge as new shoots close to the plant. This habit of growth results in plants that are compact with closely spaced culms. Selection for the non-spreading habit fortunately gave also more compact plants, and plants which were invariably more leafy.

A mixture of the non-spreading strain of brome-grass and alfalfa seeded at 25 and 5 lb. per acre, respectively, is expected to provide the best all-round hay and pasture crop for the parkland soils of the three western provinces.

Slender Wheat-grass.—This indigenous species was first cultivated in 1885. Tests conducted at the Dominion Experimental Farm, Brandon, Man., indicated that this grass possessed valuable characteristics as a cultivated crop. It rapidly became the most popular grass for hay throughout the West.

Improvement work began in 1913 when Dr. M. O. Malte [12], then Dominion Agrostologist, made single-plant selections from the numerous forms which he found growing in the neighbourhood of Edmonton, Alberta. When Dr. G. P. McRostie took over the work at Ottawa in 1922 he received from his predecessor 'a few superior strains of slender wheat-grass'. These were tested at the Dominion Experimental Station, Scott, Sask., one of them later being released as a combined hay and pasture type under the variety name 'Grazier'. Another strain known as 'Fyra' was distributed generally in 1925 by the Field Husbandry Department, University of Alberta. The latter variety was the best of a number of Ottawa strains tested at that Institution.

Improvement of slender wheat-grass was begun by the author in 1922

at the University of Saskatchewan. This breeding-project resulted in an improved strain named 'Mecca', pure seed of which is available. A paper published by the author [13] in 1929 gives an outline of the history of the breeding of slender wheat-grass and its status at that time, together with a full account of the development of the Mecca variety.

The Dominion Experimental Station at Scott, Sask., is located in a district which is especially well adapted to the growing of slender wheat-grass. Large numbers of lines have been tested there over a period of years. Three new strains have been selected and increased, and these, together with the three improved varieties mentioned above, are now being compared in special tests at Branch Experimental Stations in the three western provinces. In the meantime, brome-grass and crested wheat-grass have gained in popularity, whilst the use of slender wheat-grass is on the decline, for the time being at least.

Crested Wheat-grass.—For several years following 1915, when the first introductions of crested wheat-grass were made, we were but mildly interested in this species. Only after a succession of very dry seasons did we begin to appreciate how valuable it could become as a cultivated grass for hay and pasture in the semi-arid sections. Many years were devoted to a study of its natural range of adaptation, longevity, drought-resistance, root-development, response to continuous grazing under range conditions, and the best methods of securing good 'catches'. Crested wheat-grass is just now coming into general use. In 1935 well over 300,000 lb. of seed were produced for sale, mostly in Saskatchewan. It is estimated that 90 per cent. of this consisted of the improved 'Fairway' strain, 50,000 lb. of which were sealed in the sack as registered seed. That the demand for seed is far from being satisfied is indicated by the fact that prices paid to growers ranged from 28 cents per lb. for commercial crested-wheat seed to 45 cents for registered seed. Yields of 300 to 800 lb. of seed per acre have been quite common during the past season.

The Fairway strain of crested wheat-grass differs markedly from that of any of the numerous introductions which have been tested, especially with respect to its non-tufted habit of growth, the broad dense type of head, which always carries short awns, and the relatively small seed, as compared with that of ordinary crested wheat-grass. In the very dry ranching areas, where the ground-cover of native grasses is normally sparse, the Fairway strain probably has little advantage over the common sorts, but where the available soil moisture is a little more plentiful, the Fairway strain makes a closer turf and a finer growth, which is advantageous, especially for grazing. At Saskatoon it has consistently outyielded the tufted and taller types.

It has been shown also that crested wheat is a very useful turf grass for lawns, town boulevards, playgrounds, and fairways in the dry areas of western Canada, where appliances for artificial watering are not available. For these purposes the Fairway strain is especially desirable, as it makes a smoother and less tufted turf.

Crested wheat-grass produces seed almost entirely by cross-fertilization. Inbreeding results in pronounced loss in vigour of growth, and

many of the inbred lines contain albino seedlings. The species is conspicuous for its very wide range of variability in plant-type. It has been rather surprising, therefore, to find that the Fairway strain has retained its distinctive characteristics. Since the early breeding nurseries contained many introduced strains, occasional admixtures of other plant-types due to natural crossing might have been expected. The explanation seems to be that the Fairway strain has only 14 chromosomes, whereas the taller tufted types have 28. The chromosome counts were made but recently, and on only a few individuals, but if this holds generally, as we believe it does, there is a reasonable chance that natural crossing does not take place between the Fairway strain and dissimilar types of crested wheat. It follows also that the original mass selection was probably made from a single introduction. Unfortunately, all of the records were lost by fire in 1925; but since there were several hundred single plants each, of several introductions in the breeding nursery, this might easily have been the case. This is not surprising since any improvement-work which has been attempted in recent years has always led us to select within the Fairway rather than any other strain. Its superiority in single-plant nurseries, as well as in test plots, at Saskatoon is very obvious.

The results of investigations with crested wheat-grass have appeared in two bulletins [14, 15]. The later publication supersedes the first.

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THE FEEDING-VALUE OF PASTURES SOWN WITH DIFFERENT STRAINS OF GRASSES AND CLOVERS

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During the present century considerable interest has been taken in the improvement of grassland. A very large number of the investigations made have, however, been carried out on small plots, the results being expressed in terms of hay or dry grass. From such experiments one can calculate the monetary value of improvements on hay-fields, hay being a marketable product. In the case of grazing-fields, however, animal products—milk, meat, and wool—and not grass, are the marketable materials. Thus, in order to ascertain the value of any improvement in a pasture the herbage must be converted into these products, and the improvement measured either by the live-weight increase or by the milk-production of animals grazing on such pastures. As both these products are marketable it is possible, once the yields are known, to calculate whether certain improvements are economically sound at any given moment.

The first experiment designed to express the increased value of improved pastures in terms of animal products was initiated by Somerville [1] at Cockle Park in 1897. In that experiment the improvement resulting from the use of manures was shown as the increased live-weight production obtained, compared with that of the unimproved sward. This was further expressed in money value, 1 lb. increase in live-weight being reckoned to be worth 3*d*. Following Somerville's experiment several others were started on similar lines between 1900 and 1904 [2], and these also expressed the improvements effected by manures as live-weight increase of sheep. In experiments carried out later cattle were used, the improvements due to manuring being measured by milk-production [3, 4, 5] and by increase in weight [6].

Until the last few years little was known of the relative feeding-value of different grasses and clovers, although it was generally realized that the inclusion of wild white clover in a seeds-mixture had a marked effect on the resulting sward [7, 8, 9]. Somerville [2] attributed part of the increased mutton-production on the slagged plots to the increase in white clover, but the value of this species could not be definitely ascertained as it was not known how much was due directly to slag and how much to white clover. Roberts [10], dealing with a pasture in its third and fourth harvest years, showed that the inclusion of wild white clover gave an increase of 36 per cent. and 22 per cent. respectively in the live weight of cattle and sheep. The present writer [11], using sheep only, showed that swards consisting chiefly of perennial rye-grass with wild white clover, and bent with wild white clover, gave about 200 lb. more increase in weight than cocksfoot plots which contained little or no white clover. This difference represented an increase of over 70 per cent. It was also shown that the increased live-weight obtained from

the white-clover plots was greater than would be expected on the basis of increased yield of herbage as such; thus suggesting that a mixture of grasses and clover has a higher feeding-value than a mixture consisting of grasses only.

To obtain more information about the feeding-value of different species, and groups of species, a new experiment was laid out on a 10-acre field in May 1931. The field had been through the ordinary farm rotation, viz. grass followed by cereal crops in 1928 and 1929, a root crop in 1930, and 'seeds' sown under barley in 1931. Eight acres of this field were divided into 48 plots, each measuring 18 by 45 yds. ($\frac{1}{6}$-acre). Eight different seeds-mixtures were sown, each being replicated six times. The experiment will be dealt with in two parts: Part I relating to six ultra-simple seeds-mixture, and Part II to two complex seeds-mixtures.

Part I. EXPERIMENTS WITH VERY SIMPLE SEEDS-MIXTURES

The six simple mixtures were made up as follows in lb. per acre:

Mixture 1.	Perennial rye-grass*	35
Mixture 2.	Cocksfoot†	35
Mixture 3.	Perennial rye-grass*	17½
	Cocksfoot†	17½
Mixture 4.	Perennial rye-grass*	30
	Wild white clover	5
Mixture 5.	Cocksfoot†	30
	Wild white clover	5
Mixture 6.	Perennial rye-grass*	15
	Cocksfoot†	15
	Wild white clover	5

* Seed from Kentish old pastures.

† Strain of cocksfoot (S 26) bred at the Welsh Plant Breeding Station.

Although the nurse crop (barley) gave a very heavy yield, yet the 'take' of the grasses was exceptionally good. A close examination of the sward in April and early May of the first grazing season showed the presence of the white clover as very small plants or seedlings on the plots where it was sown, but none could be found on the other plots. However, owing to slow growth its contribution to the pastures where it was sown was negligible until the end of May and early June of the first grazing-season. After that period, and during the following three seasons, its contribution to the herbage of the plots where it had been sown was considerable, though it varied from plot to plot and from year to year. This point will be dealt with in greater detail in a subsequent communication. It will suffice here to state that the contribution of white clover was negligible on almost all plots except those where it had been sown, and that it varied in amount from plot to plot even where it had been sown, being far more productive when associated with perennial rye-grass than with cocksfoot; in fact, there was only a trace of it on certain cocksfoot plots in the first two years.

Stock used and method of grazing.—Grazing was carried out exclusively by sheep, which were tethered: about 110 lambs were bought every autumn and wintered on an adjoining farm; they were brought from

their winter quarters about a week before the grazing on the plots was begun. During this week they were weighed on three successive mornings after a fast of 16 hours. Occasionally there was a fourth and even a fifth weighing if the first three weighings did not agree. Any sheep that showed signs of being abnormal in any way were rejected, together with those that were outstandingly large or outstandingly small. The remaining sheep were then divided into eight groups of twelve, each group being similar in size, type, and condition.

Grazing usually began in the latter part of April, one pair of sheep being tethered on every plot that had a sufficient growth of herbage to maintain them at that time; the remainder of the plots were stocked later. Each pair of sheep was shifted forward 2 yards each morning and each night. The length of chain was such that only half the width of the plot was grazed when the sheep were shifted forward, the other half being grazed as the animals moved in the opposite direction about 10 days later. This arrangement made it possible for all areas to have a 3 weeks' rest between each grazing. Usually during May and June each plot was grazed by a pair of sheep, but in July and August it frequently happened that a number of pairs had to be removed owing to a shortage of food. The object in view during the grazing was to keep the number of sheep at such an intensity as to avoid any wastage of herbage, and at the same time to satisfy the needs of the sheep. All sheep that were removed were again weighed on three successive mornings, in each case after 16 hours' fasting, and any further growth of herbage on those plots would be shared between the most needy pairs of the other five replicates. It was found in some mixtures that towards the end of August and during September three pairs of sheep could eat all the herbage on the six replicates of their mixture, whereas other mixtures were quite able to supply the needs of the six pairs of sheep. In addition to the first and final weighings, the sheep were also weighed when released for shearing, and again prior to dipping; all weighings followed a 16-hours' fast.

Discussion of Results

Live-weight increase

(*a*) *Effect of wild white clover on live-weight production.*—The increase in live-weight of the sheep on the different mixtures is shown in Table 1. It is seen that in four years the sheep grazing on the plots in which wild white clover had been sown gained on an average 224 lb. per acre more than those grazing on the plots where the wild clover had been omitted from the seeding. This represents a difference of 56 lb. per acre per year in favour of sowing wild white clover.

A comparison of the live-weight increase of sheep grazing on the plots sown with grasses and wild white clover and those sown with grasses only is also shown in Table 2, in which the figures represent the percentage increases due to wild white clover.

Thus, during the whole period of four years, the increase in live-weight due to the clover was much higher on the rye-grass plots than on the cocksfoot plots, the rye-grass–cocksfoot plots being intermediate.

TABLE 1. *Increase in Weight of Sheep grazing on Swards of Different Composition*

(lb. per acre per annum)

Plot	*1932*	*1933*	*1934*	*1935*	*Total for four years*
Rye-grass	263	169½	170¾	195¼	798½
Cocksfoot	240	165¼	160½	164	729¾
Rye-grass and cocksfoot	260	179¾	175½	187¼	802½
Average of plots without clover .	254¼	171½	169	182¼	777
Rye-grass and wild white clover . .	313	245	263¼	244¼	1065½
Cocksfoot and wild white clover . .	279	186	232½	203¾	901¼
Rye-grass, cocksfoot, and wild white clover	285	223	263	265½	1036½
Average of plots with clover . .	292	218	253	238	1001

TABLE 2. *Percentage Increases in Live-weight Production obtained on the Plots Sown with Grasses and Wild White Clover above those obtained on the Plots Sown with Grasses only*

Year	*Percentage increase due to wild white clover on*			
	Rye-grass	*Cocksfoot*	*Rye-grass and cocksfoot*	*Average*
1932 . .	19·0	16·2	9·6	15·0
1933 . .	44·7	12·5	24·0	27·1
1934 . .	54·1	45·0	50·2	49·8
1935 . .	25·1	24·4	41·7	30·6
Average .	33·4	25·0	29·4	28·8

A comparison of the different years shows that the highest percentage increase due to wild white clover was obtained in the third grazing-season (50 per cent.) and the lowest in the first grazing-season (15 per cent.). The second and fourth grazing-seasons gave on the average a similar increase, yet wild white clover contributed far more to the live-weight increase of the rye-grass plots in the second season, whereas on the cocksfoot and the rye-grass–cocksfoot mixture it was much more effective in the fourth year. This corresponds roughly with the productiveness of the white clover, the third year being the best and the first year the poorest for the growth of clover. In addition the amount of white clover on the rye-grass plot greatly exceeded that on the other plots in the first and second years, but by the fourth year it had disappeared from two of the rye-grass plots, whereas its productivity on the cocksfoot and rye-grass–cocksfoot plots was better maintained.

(*b*) *The effect of species on live-weight production.*—The superiority of rye-grass for live-weight production (Table 1) is shown more strikingly in Table 3, where all values are given on the basis of cocksfoot = 100.

TABLE 3. *Comparative Live-weight-increases of Sheep grazing on Plots of Rye-grass and Cocksfoot*

(*Cocksfoot in all cases* = 100)

	Grasses only	*Grasses and wild white clover*	*Average*
Cocksfoot . . .	100	100	100
Rye-grass . . .	109·4	118.2	114·3
Rye-grass and cocksfoot .	110·0	115·0	112·7

Condition of sheep.—In addition to being weighed, all sheep were graded according to condition in 1932 and 1935. This was done at the final weighing. The animals were divided into three main grades as follows:

Grade 1: fat.
Grade 2: all fit for killing but slightly inferior to Grade 1.
Grade 3: stores and not suitable for killing.

Each grade was further subdivided, but these three main grades serve to show the trend of condition of the animals on these plots. In 1933 and 1934 the drought interfered with grazing, which was not continuous throughout the season in either year, so that grading would not have served any useful purpose.

The results of grading, given in Table 4, show the superiority of the clover over the non-clover swards, and of rye-grass over cocksfoot swards in the fattening of the sheep. This indicates that the higher live-weight increases obtained on certain plots, as shown in Tables 1, 2, and 3, were primarily due to fattening rather than to body-growth.

TABLE 4. *Condition of Sheep after grazing on Different Swards* (*Results for 1932 and 1935*)

	First grade	*Second grade*	*Third grade*
Rye-grass	7	8	9
Cocksfoot	0	11	13
Rye-grass–cocksfoot	6	8	10
Totals, plots without clover	13	27	32
Rye-grass and wild white clover	11	12	1
Cocksfoot and wild white clover	7	12	5
Rye-grass, cocksfoot, and wild white clover . .	11	12	1
Totals, plots with clover	29	36	7
All rye-grass plots.	18	20	10
All cocksfoot plots	7	23	18
All rye-grass–cocksfoot plots	17	20	11

Carrying-capacity of the pastures.—In addition to differences in live-weight increments, it was found that certain plots were able to maintain the stock for longer periods than others. Although this is partly reflected in the figures for live-weight increase, yet earlier spring grazing and grazing available during periods of drought have a special maintenance-

value which should be calculated quite apart from production, as shown in Table 5. These figures indicate that the average carrying-capacity of the clover plots was 193 'sheep-days' per acre per year, or 14·5 per cent. greater than that of the non-clover plots. Within the non-clover plots, and also within the clover plots, the difference in the carrying-capacity of the various grasses was very small—less than 2 per cent.

TABLE 5. *Carrying-capacity of the Pastures in 'Sheep-days' per acre per annum*

	1932	*1933*	*1934*	*1935*	*Average per annum*
Rye-grass	1697	1156	948	1506	1327
Cocksfoot	1682	1190	894	1466	1308
Rye-grass and cocksfoot	1722	1190	948	1506	1341½
Average	1700	1179	930	1493	1325
Rye-grass and wild white clover	1872	1458	1160	1616	1526½
Cocksfoot and wild white clover	1822	1458	1114	1616	1502½
Rye-grass, cocksfoot, and wild white clover	1862	1458	1160	1616	1524
Average	1852	1458	1145	1616	1518
Average increase due to wild white clover	152	279	215	123	193
Percentage increase due to wild white clover	9·0	23·6	23·1	8·2	14·5

Roberts [10] states that in the experiment he described the extra live-weight increase was mainly due to a greater stock-carrying capacity on the wild white clover plots. In the present experiment, however, the clover plots compared with the non-clover plots gave on an average nearly 30 per cent. more live-weight increase, whereas the carrying-capacity was only approximately 15 per cent. higher. These data show that in addition to increased carrying-capacity the white clover had increased the feeding-value of the herbage. This is also borne out by the results of a previous experiment [11].

Rainfall during the Four Grazing Seasons, 1932–5

The experiment was conducted in a district situated about mid-way between Aberystwyth and St. Anne's Head, Pembrokeshire, where the nearest weather-recording stations are situated. The rainfall in inches between the 1st of April and the end of September for these two stations was:

	1932	*1933*	*1934*	*1935*
Welsh Plant Breeding Station*	16·97	8·94	19·10	26·14
St. Anne's Head*	14·31	13·10	11·41	14·86
Average	15·64	11·02	15·25	20·50

* These values were calculated from data extracted from the monthly weather reports of the Meteorological Office.

These figures show that the rainfall differed markedly at the two stations. Apart from 1934, however, the average figures as shown above

would give approximately the rainfall during the experiment. The rainfall for 1934 would be nearer to the value given for St. Anne's Head, or even less than that. This difference in rainfall, however, does not give a true picture of the wetness or dryness of the different years, 1933 and, especially, 1934 being classed as two dry years, whereas 1932 and 1935 would be classed as wet years.

The above tables show that in the comparatively 'wet' years (1932 and 1935) the average increase in weight per acre (all plots) was 241½ lb., whereas in the 'dry' years (1933 and 1934) it was only 203 lb. per acre. This represents an increase of about 19 per cent. more production in the wet years than in the dry years. The average carrying-capacity was 1,665 'sheep-days' in the wet years, and only 1,178 'sheep-days' in the dry years. This is equivalent to an increase of 41 per cent. in the carrying-capacity during wet years as compared with the dry years. Thus the greater growth of herbage in the wet years increases the carrying-capacity of the pastures more than their live-weight production. It is also seen that although the wet years have a greater total increase in live-weight, yet the live-weight increase per sheep-grazing-day was lower than in the dry years.

Part II. EXPERIMENTS WITH COMPLEX SEED-MIXTURES

In the second part of the experiment two complex mixtures were compared, one consisting mainly of indigenous grasses and clovers, the other of the ordinary commercial strains. The mixtures were made up as follows in lb. per acre:

	Commercial mixture	*Indigenous mixture*
Perennial rye-grass	14	12
Italian rye-grass	5	5
Cocksfoot	3	8
Timothy	4	2
Meadow-fescue	2	..
Crested dogstail	..	2
Rough-stalked meadow-grass	..	2
Wild white clover	..	2
Dutch white clover	1	..
Red clover	4	4
Alsike	1½	..
Trefoil	1	..

In the commercial mixture the red clover was composed of three parts broad red to one part of late-flowering red clover.

In the indigenous mixture the red clover was the Montgomery strain; white clover was all genuine 'wild' white; perennial rye-grass was obtained from old Kentish pastures; cocksfoot and timothy were strains bred at the Welsh Plant Breeding Station.

The mixture of commercial strains represents the average type of seeds-mixture sown by farmers in this area. Although the seeds-mixture varies from farm to farm, yet in a large number of lists examined it was found that commercial strains of rye-grass, cocksfoot, timothy, and meadow-fescue were used together with Dutch white clover, broad red

and late-flowering red clovers, alsike, and trefoil. Wild white clover, rough-stalked meadow-grass, and crested dogstail were nearly always excluded.

In the indigenous mixture a modified form of the Cockle Park mixture was sown as recommended by Stapledon and Davies [12]. Wherever possible improved strains were used, but with many species only the ordinary strains were available.

In the first grazing season four plots of each mixture were kept for hay and then grazed, and again in the fourth grazing season one plot of each was similarly treated.

TABLE 6. *Comparison of the Productiveness of the Commercial Mixture and the Indigenous Mixture as* (a) *Increase in Live-weight in lb. per acre;* (b) *Carrying-capacity expressed in 'Sheep-days', and* (c) *Yield of Hay on Ungrazed Areas (1932 and 1935)*

Mixture	*1932*	*1933*	*1934*	*1935*	*Total*
(*a*) *Increase in live-weight:*					
Commercial	122	202½	192¼	177¾	694½
Indigenous	156½	238¼	227½	205½	837¾
(*b*) *Carrying-capacity:*					
Commercial	1,065	1,250	948	1,330	4,593
Indigenous	1,215	1,458	1,160	1,430	5,263
(*c*) *Yield of hay* in cwt.:*					
Commercial	21¾	..	..	4	25¾
Indigenous	23	..	..	5	28

* On ungrazed plots.

A comparison of the production of these two plots is given in Table 6, from which it is seen that the increase in the live-weight of the sheep, the carrying-capacity, and the hay-production, were higher for the indigenous than for the commercial mixture for every year in which figures were available.

The total increased live-weight production for the indigenous mixture was about 143 lb. per acre, or about 36 lb. per acre per annum. This represents an increase of 20 per cent. over the commercial mixture.

The total increased carrying-capacity for the indigenous mixture amounted to 670 days, or about 168 sheep-days per acre per annum. This is equivalent to an extra carrying-capacity of about 0·46 sheep per acre for a whole year, or an increase of 14·6 per cent. over the commercial mixture. The hay harvested from the ungrazed plots in 1932 and 1935 amounted to 25¾ cwt. for the commercial mixture, and 28 cwt. for the indigenous mixture; the latter, however, was far more leafy and probably of greater feeding-value.

Fagan [13] has shown that grass leaves are more nutritious than stems. In addition, Stapledon [14] has established that the indigenous strains of grasses, particularly perennial rye-grass, cocksfoot, and timothy are far more leafy and longer lived than their commercial counterparts.

These facts are borne out by the present experiment, in that the indigenous mixture of grasses and clover has given higher increases in the live-weight of sheep than the commercial mixture.

Financial aspect of the results.—A comparison of the possible financial returns is shown in Table 7. In arriving at these figures it has been assumed that each pound of live-weight increase of sheep is worth 4*d.*, and that hay standing in the field is worth £2 per ton. These values must of necessity change with any fluctuations in market prices.

Although the mixtures of grasses and wild white clover cost considerably more than those not containing clover, the extra production

TABLE 7. *Financial Returns per acre for the Sum of Four Seasons*

	Cost of mixture	*Total live-weight increase lb. per acre*	*Value of live-weight increase at 4d. per lb. in shillings per acre*	*Value of hay in shillings per acre*	*Total value of produce in shillings per acre*	*Total value less cost of mixture*
	s. d.		*s. d.*	*s. d.*	*s. d.*	*s. d.*
(*a*) *Comparison of:*						
Grasses only	43 9	777	259 0	..	259 0	215 3
Grasses and wild white clover	62 6	1,001	333 8	..	333 8	271 2
Increase due to wild white clover	18 9	224	74 8	..	74 8	55 11
b) *Comparison of:*						
Commercial mixture	22 0	695	231 8	51 6	283 2	261 2
Indigenous mixture	54 0	838	279 4	56 0	335 4	281 4
Increase of indigenous mixture over commercial	32 0	143	47 8	4 6	52 2	20 2
Simple mixture of rye-grass and wild white clover	62 6	1,065½	355 2	..	355 2	292 8
Increase of simple mixture over commercial	40 6	370½	123 6	−51 6*	72 0	31 6

* No hay cut; hence the value of hay cut on the commercial mixture is entered as a minus quantity.

of live-weight on the plots of the former more than repaid this increased original outlay; in fact there was a profit of about 56*s.* per acre in favour of wild white clover. In addition it should be pointed out that wild white clover had been sown at the unusually heavy rate of 5 lb. per acre in order to be certain of a sward rich in clover. It is very probable, however, that equally good results would have been obtained by sowing 2 lb. of wild white clover, thus reducing the cost of the clover mixtures by 15*s.* per acre.

If the ordinary farmer's mixture of grasses and clovers is taken as a basis, the mixture of indigenous strains of grasses and clovers, despite its higher seed cost of 32*s.* per acre, more than repaid this additional cost, and still left a profit of about 20*s.* per acre. The best return, however, was obtained from the simple mixture of perennial rye-grass and wild white clover. Though its seed cost was 40*s.* per acre higher than that of the farmer's mixture, yet it left a profit of 31*s.* 6*d.* per acre.

It will be noted that no value has been given to the extra carrying-capacity. Although this is partly reflected in the live-weight increase,

yet in the early spring and during periods of drought it has a special value, and at such times ½*d.* per sheep per day is not too much. In this experiment the extra sheep-carrying capacity is distributed over the growing-season, but is more pronounced during the critical periods mentioned above. On that account it would not be unfair to value this extra sheep-carrying capacity at about half the normal rate. This would increase the money value of the clover plots over the non-clover plots by about 16*s.*, giving a total in favour of sowing white clover of about 72*s.* per acre in four years. In the comparison between the commercial mixture and the indigenous and simple mixtures, both the latter plots would have an increased value of about 14*s.* per acre over the commercial mixture. This would bring the balance in favour of the indigenous mixture to 34*s.* 2*d.*, and that in favour of the simple mixture to 45*s.* 6*d.* per acre as compared with the returns of the commercial mixture. Thus the most economic returns financially and agriculturally have been obtained by sowing:

(*a*) wild white clover,
(*b*) indigenous strains of grasses and clover,
(*c*) rye-grass in preference to cocksfoot.

Summary

An account has been given of an experiment designed to test the value of different types of seeds-mixtures in the production of live-weight increments in sheep. It has been shown that:

1. Grasses in combination with wild white clover (*a*) were nearly 30 per cent. more productive in live-weight increments, and (*b*) had a carrying-capacity nearly 15 per cent. higher than those sown without the white clover.

2. Perennial rye-grass was about 14 per cent. more productive in live-weight increase but had the same carrying-capacity as cocksfoot.

3. A complex mixture of indigenous grasses and clover gave much larger increases in live-weight and also gave a higher carrying-capacity than a mixture of commercial strains.

4. The increase in live-weight of sheep per grazing day was greater in the 'dry' years than in the 'wet' years, yet the total increase in live-weight per acre per grazing-season was greater in the wet years; this being due to the longer grazing afforded during the wet seasons.

An attempt has been made to convert the results obtained into money value; this has shown that certain mixtures of grasses and clovers give far better returns per acre than others.

The experiment is still in progress; further results will be published in due course.

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THE YIELD AND COMPOSITION OF CUT PASTURE HERBAGE AT DIFFERENT TIMES OF THE DAY

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Introduction.—The amount of water in pasture herbage, as is well known, may vary appreciably during the day, depending largely upon the immediate weather conditions. This fact is naturally one of practical and economic importance in the conservation of grass by artificial drying, where a low moisture-content, or water ratio,[1] in which form it is usually expressed, means a saving in the costs of both carting and drying, and an increased output of dried material. For these reasons, and where preliminary drying in the field (*this J.*, 1936, **4**, 145), is not practised it would seem advantageous to cut the grass at that time of the day when its moisture-content is lowest.

Although various workers have investigated diurnal variations in the water-content and in the composition of certain plants, most of their work has been concerned with variations as between day and night, and with plant-physiological problems having little direct bearing on the present question. The only relevant study of herbage plants, so far as the author is aware, was made in 1934 at Billingham, on herbage from the farm adjoining the factory of I.C.I. (Fertilizer and Synthetic Products) Ltd.[2] It was there found that the water-content of grass depended on the time of year, the nature and stage of its growth, and on the immediate weather conditions. On sunny days in May the water ratio fell considerably during the day, the lowest values occurring between 11 a.m. and 3 p.m., but on cold or dull days and at the end of the season, little diurnal variation occurred. Also, the moisture-content of older tissue was lower than that of young growth.

The object of the tests here described was to study diurnal variations in the moisture-content of grass under different weather conditions and at different times of the season, in order to ascertain the best time of day at which to cut grass for artificial drying. At the same time the opportunity was taken of studying whether, and if so to what extent, variations occurred in the yield of herbage cut, and in its contents of dry matter and nitrogen.

The Investigation.—The tests were conducted at Jealott's Hill on five days during the grass-drying season of 1935, all within a small area of good-quality pasture in Copse Meadow, on grass which was either being cut at the time for drying, or was at a stage of growth suitable for drying.

Three plots,[3] each 18 in. square and randomized in three blocks, were cut at 9.30 a.m. on each day, and further series of three plots were cut at 1½- or 2-hourly intervals throughout the day until 5 p.m., when the last plots were cut. Cutting was done by hand with a pair of sheep-

[1] Ratio of water to dry matter. [2] Private communication.

[3] The plots were laid out to avoid any side- or edge-effects, at least a 1 ft.-width of uncut grass being left around each plot.

shears, and the herbage was cut uniformly to within about 1 in. of ground-level. To facilitate easy and uniform cutting, a wooden frame of the size of the plot, with sides 2 in. wide and ¾ in. deep, was placed over the plot to rest on the grass without pressure at about ⅛ in. above ground-level. The ends of the undisturbed grass within the frame were then held lightly, a few at a time, in the finger-tips, without any upward pull or downward thrust, which would be likely to alter the natural position of the lower parts of the shoots, and the grass was then cut with the shears held in the plane parallel to and just above the top of the frame, i.e. at about 1 in. above ground-level. The plots (except on one or two occasions) were all cut by the same person. In almost all cases the herbage was free from extraneous material; the cut herbage, however, was carefully looked over at the time of cutting, and any extraneous material removed.

The fresh herbage from each plot was weighed immediately after cutting, and then taken to the laboratory, where it was spread out in a thin layer, dried immediately to constant weight in the steam-oven, and the yield of dry matter thus determined. By drying the whole of the produce from each plot, any error in sampling the fresh grass was avoided. The percentage of nitrogen in the ground, dried material, was determined by the standard Kjeldahl method.

In many cases the grass held external moisture, which was not determined separately, and the figures given, therefore, include both the internal and any external moisture present. Visual and tactile observations were, however, made of the presence or absence of external moisture and of its approximate extent.

Conditions of Tests.—The tests were carried out at three periods of the season on the dates and under the conditions given below:

(i) May 20 and 21. First spring growth 6–8 in. high, consisting mainly of perennial rye-grass (34 per cent.) and meadow foxtail (35 per cent.) with a little of the former coming into flower, and much of the latter actually in flower. Tests carried out on consecutive days, the first wet, cold, and sunless, the second fine and sunny but cool, with a drying east wind. Field being cut for artificial drying at this time.

(ii) June 28. Growth 8–9 in. high, made since the May tests, and consisting chiefly of perennial rye-grass (47 per cent.) and Yorkshire fog (19 per cent.), both well in flower, with wild white clover (16 per cent.). Weather was warm and sunny. Field being cut for artificial drying at the time.

(iii) October 9 and 11. Growth made since June cut, but mainly new autumn growth made since August, following a dry summer, and consisting chiefly of perennial rye-grass (61 per cent.) and wild white clover (15 per cent.). 3–5 in. high. The first day was dull and windy with drizzle and rain later; the second was fine and sunny.

The meteorological readings on these days and the preceding day in each case are given in Table 1.

Soil moisture was not determined specially for this investigation, but measurements taken on adjoining pasture in connexion with other work

gave the following values for the percentage of moisture in the top three inches of soil, on, or a little before, the dates when the grass-cutting tests were made: May 20, 18·4; June 24, 19·0; Oct. 7, 25·1. On each day of the tests the soil was moist, and on no occasion did the soil appear to lack moisture needed by the grass.

TABLE 1. *Meteorological Readings*

Date	Barometer	Humidity	Screen temperature Maximum	Screen temperature Minimum	Rainfall	Sunshine	Wind direction and force
	in.	%	° F.	° F.	in.	hr.	
May 19	29·89	73	53	30	0·21	0·2	S.E. 1
„ 20	29·75	83	55	41	0·91	0·5	Calm
„ 21	29·98	75	57	39	..	10·9	E. 4
June 27	29·95	91	67	56	..	1·5	S.W. 1
„ 28	30·25	74	75	47	..	14·8	Calm
Oct. 8	29·54	93	55	42	0·27	2·1	S.W. 3
„ 9	29·64	88	59	43	0·64*	0·9	S.W. 3
„ 10	29·28	85	57	49	..	7·6	S.W. 4
„ 11	29·75	80	58	43	..	8·9	S.W. 3

* Most of this rain fell after completion of test.

The soil in Copse Meadow is a medium loam overlying clay. The manuring of the pasture in 1935 consisted of 2 cwt. of sulphate of ammonia per acre, applied on April 15.

Results.—The results are tabulated in the appendix, and include: the yields (average values of the three replicate plots) of fresh herbage, dry matter, and nitrogen; the percentage of water in the fresh herbage with the corresponding water ratio; and the percentage of nitrogen in the dry matter; together with brief notes on the weather conditions during the intervals between the cuts, and on the presence or absence of, and the approximate extent of, external moisture on the grass.

(i) *May 20 and 21.* On the fine, sunny day (May 21), the percentage of water in the cut herbage decreased significantly[1] during the latter part of the morning, between 11 a.m. and 1 p.m., with the disappearance of the external moisture originally present, and thereafter, between 1 and 5 p.m., remained unchanged. The fall in the water ratio was from approximately 4·5 to 3·5. May 20 was wet and the grass held a considerable amount of external water throughout the day, but although this amount appeared to get less during the temporarily dry period between 11 a.m. and 1 p.m., no significant diurnal change in the percentage moisture-content of the herbage was observed.

The yield data are less easily interpreted. As is inevitable with pasture herbage, where the natural yield variation is always comparatively large, the yields of the replicate plots varied appreciably, and although the average values would seem to indicate considerable diurnal variations in

[1] The term 'significant' is used throughout in the statistical sense ($P = 0{\cdot}05$), in accordance with Fisher's analysis of variance.

the yields (whether expressed in terms of fresh herbage, dry matter, or nitrogen), the variations in the yields of dry matter and nitrogen did not attain a 20 to 1 level of significance. However, on both days there was an apparent progressive and substantial falling off in these yields during the morning, with the lowest yields of the day obtaining in the 1 p.m. cut, but on the rainy afternoon of May 20 the yields apparently increased again, and on the fine afternoon of May 21 remained practically constant at the midday level.

The percentage of nitrogen in the dry matter of the herbage varied appreciably from plot to plot, and at different times of the day, particularly on May 20. The observed diurnal variations were not significant on May 20, but on May 21 the fall in the percentage value in the middle of the day, from an initial value of about 2·8 to 2·5, was apparently just significant; the value increased again in the afternoon.

(ii) *June 28.* In this test the grass was more stemmy and mature than that of the May tests (though it was fresh growth made since these tests), as will be seen also from its lower nitrogen-content; also, growth was more uniform than in May, and the individual plots in consequence showed less variation in yield. Under these conditions, and on a warm, sunny day, the only significant diurnal change observed was a reduction in the percentage of water in the fresh herbage during the morning, as the dew disappeared; the fall in the water ratio was from 4·4 to 3·7 approximately. After midday the moisture-content of the grass remained unchanged. No significant change was observed during the day in the yields of dry matter or nitrogen, or in the percentage of nitrogen in the dry matter.

(iii) *October 9 and 11.* Under the autumn conditions of Oct. 9, during a dull but windy morning after rain overnight, the moisture-content of the herbage fell significantly, with the disappearance of the external moisture present, until the lowest value of the day was obtained in the 2 p.m. cut; the fall in the water ratio was from 5·1 to 3·3. When rain fell later the moisture-content increased to the value of the early morning. The test of October 11 differed from the four previous ones in that the grass initially held practically no external water; under these conditions and during a generally fine, sunny day, no significant change in the moisture-content of the grass was observed.

Growth in October was again somewhat uneven and the individual plot-yields in consequence were again somewhat variable. No significant change was observed in the yields of dry matter or nitrogen on Oct. 11, but on Oct. 9 (as on May 20 and 21) there was an apparently substantial reduction in the yield (whether expressed in terms of fresh herbage, dry matter, or nitrogen) in the middle of the day (between 11 a.m. and 2 p.m.), with an increase again (including increased yields of dry matter and nitrogen) in the later afternoon cuts. It is to be noted, however, that as on May 20 and 21, this apparent diurnal variation in yield does not attain the level of significance of 20 to 1, though the level attained on Oct. 9 falls little short of this value.

Neither on Oct. 9 nor 11 was there any significant change during the day in the percentage of nitrogen in the dry matter of the herbage.

Discussion

The significance of the percentage water-content of the grass in its conservation by artificial drying is well shown by the following figures:

Water, per cent.	85	80	75
Dry matter, per cent.	15	20	25
Water ratio	5·7	4·0	3·0

Thus a relatively small reduction in the percentage of water in the grass means a comparatively large increase in the proportion of dry matter which is being cut, collected, and carted, and a corresponding reduction in the amount of water which has to be evaporated per unit of dry matter present. The tests described have shown that under a variety of weather conditions and at different periods of the grass-drying season, a considerable reduction in the percentage of water in the grass normally occurs during the day, and that under the conditions investigated the percentage generally reached its lowest value of the day sometime between noon and 3 p.m. This reduction in moisture-content was apparently associated almost exclusively with the disappearance of external moisture usually present in the herbage early in the day, little or no change being observed when external moisture was absent.

For practical purposes, under conditions generally similar to those under which these investigations were conducted, it may be concluded that if the grass contains any appreciable amount of external moisture in the early morning, most of this moisture will have disappeared by about midday (unless it has rained meanwhile), and that any subsequent reduction in the moisture-content will be of little or no practical significance. The most suitable hours for cutting grass, under these conditions, to ensure a minimum moisture-content, would appear, therefore, to be from about noon or a little earlier, to 3 p.m. or later, should the grass remain free of external moisture. Where the grass is more or less free of external moisture initially in the morning, there will probably be but little advantage if cutting is postponed until later in the day. The general accordance of these results with those obtained under other conditions at Billingham (*v.s.*) in 1934 is noteworthy.

On none of the days when the tests were made was the weather hot, and the results, although apparently applicable to the weather conditions usually obtaining under grass-drying practice, cannot, pending further tests, be taken to apply to conditions of heat and drought in which there may be some diurnal variation in the internal moisture of the herbage, though no evidence of it was apparent in any of the present tests.

The apparent diurnal variations in yield (apart from variations in the fresh weight consequent upon variations in the amount of moisture in the herbage) observed in three of the five tests, cannot at present be held to point to any definite conclusions. Such large diurnal variations in the yields of dry matter and of the nitrogenous constituents as those apparently observed, are certainly not to be expected, and the statistical analysis of the data shows them to be below the 20 to 1 level of significance, though this level is closely approached in the test of Oct. 9. At the same time, the association of high yields with the initial (9.30 a.m.) cut and

of low yields with the midday cuts, in these three tests, would not seem to be entirely due to chance; and an analysis of the conditions under which these apparent diurnal yield-variations occurred would seem to suggest a direct and close relation between the yields (including the yields of dry matter and the nitrogenous constituents) at any time of the day and the amount of external water present on the herbage.

Thus, in each of the tests of May 20 and 21 and of Oct. 9, the high yields (whether expressed in terms of fresh herbage, dry matter, or nitrogen) in the initial (9.30 a.m.) cut were associated with the presence of considerable external moisture on the herbage (and in consequence with a high moisture-content of the fresh herbage), whilst the reduced yields in midday were associated with the partial or complete disappearance of this external water (and so with a reduction in the percentage moisture-content of the fresh herbage). Further, the subsequent increases in the yields in the afternoons of May 20 and Oct. 9 were on both days associated with the onset of rain (and so with an increased moisture-content of the fresh herbage due to the presence of external moisture), whilst in the afternoon of May 21, when the weather continued fine, with no change in the moisture-content of the fresh herbage (no external moisture present), there was no change in the yield values. In the test of Oct. 11, when practically no external water was present at any time of the day, no diurnal variation was observed in either the moisture-content of the fresh herbage or the yield-values, though on the other hand, on June 28 a significant reduction in the moisture-content of the fresh herbage, with the disappearance of the dew, was observed during the morning, with no change in the yields of dry matter or of the nitrogenous constituents. It would seem, therefore, apart from the results of the June 28 test, that variations in the amount of external moisture on the herbage during the day influenced in some way the actual yield of herbage (including dry matter and nitrogenous constituents) obtained at different times of the day under the conditions of cutting employed.

Pending further investigations, however, and for the reasons given earlier, it is felt that the reality or otherwise of these apparent diurnal variations in yield must remain an open question.

Whereas the apparent relation, just discussed, would seem to suggest that changes in the percentage of moisture in the fresh herbage during the day were able in some way to influence the actual yield of herbage (whether expressed in terms of fresh herbage, dry matter, or nitrogen) obtained under the cutting conditions employed, definite evidence of the existence of a separate relation between these two values is also afforded by certain of the results from individual plots for those cuts taken when external moisture was present on the herbage in appreciable amount, and more particularly in the tests of May 20 and 21. In these cases, a close direct relation was observed between the moisture-content of the fresh grass *from individual plots* and the *plot* yield, whether expressed in terms of fresh weight, dry matter, or nitrogen. It would, of course, be expected that the density of growth, and, therefore, the amount of grass present per unit area would influence the actual extent to which external water would be held, and it seems probable that this relationship between

percentage moisture-content and plot yield, when external moisture was present in appreciable amount, was due to this cause.

From the results of the tests it would appear that there will not usually be any significant diurnal variation in the nitrogen-content of the dry matter of the herbage, though the apparently significant fall in this value in the middle of the day, in the test of May 21, suggests the need of further study.

Finally, we suggest the need of investigating the yield and composition of cut pasture herbage at different times of the day, under weather conditions differing from those of the present tests, and more particularly under drier and hotter conditions.

Summary

Replicated, small-plot field tests carried out at Jealott's Hill on five days under varying but generally normal weather conditions in May, June, and October 1935, in which pasture herbage at a stage of growth suitable for conservation, was cut at 1½- or 2-hourly intervals throughout the day, to within 1 in. of ground-level, showed that the percentage moisture-content of the cut herbage normally fell significantly during the day, reaching its lowest value between noon and 3 p.m. This reduction was apparently associated almost entirely with the disappearance of external moisture usually present on the herbage early in the day.

Some evidence was obtained of an apparent diurnal variation in the yield of herbage. In three out of four of the tests where external moisture was present on the herbage in appreciable amount at some time of the day, an apparent close, direct relation between variations in the amount of this moisture and variations in the yield of herbage, whether expressed in terms of fresh herbage, dry matter, or the nitrogenous constituents, was observed; thus, high yields were apparently associated with the initial morning cut, and substantially lower yields with the midday cuts, and in the afternoon the yields (including those of dry matter and the nitrogenous constituents) increased again under rainy conditions and remained at their midday level under fine weather conditions. On the other hand, these apparent diurnal yield-variations were not in any instance statistically significant, judged on the probability level of 20 to 1, though sometimes nearly so; their reality therefore needs further investigation. In four out of the five tests no significant diurnal variation in the percentage nitrogen-content of the dry matter of the herbage was observed. In one test, in May, there was an apparently significant fall in this value in the middle of the day.

The application of our results in the conservation of grass, particularly by artificial drying, is discussed, and further investigation is suggested.

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APPENDIX

Yields of Fresh Herbage, Dry Matter, and Nitrogen. gm. per 18 in. square plot (average of 3 replicates)
Average Percentage of Water in Fresh Herbage, and corresponding Water Ratio
Average Percentage of Nitrogen in Dry Matter

Constituent	Time of cutting. Weather and grass conditions*					Standard error	Value of Z	
	9.30 a.m.	11 a.m.	1 p.m.	3 p.m.	5 p.m.		Found	Fisher's Table ($P = 0{\cdot}05$)
MAY 20								
	Showery	*Showery*	*Dull, but no rain*	*Heavy rain*	*Heavy rain*			
	Grass very wet	*Very wet*	*Wet*	*Very wet*	*Very wet*			
Yield of fresh herbage	340	249	169	253	..†	..	..	..
Yield of dry matter	58·7	46·4	33·3	46·3	..	5·56	0·623	0·780
Yield of nitrogen	1·88	1·29	0·88	1·31	..	0·195	0·748	0·780
Percentage of water in fresh herbage	82·6	81·3	79·9	81·6	81·7	0·569	0·513	0·673
Water ratio	4·75	4·35	3·98	4·44	4·46	..	..	..
Percentage of nitrogen in dry matter	3·16	2·76	2·64	2·81	2·88	0·144	0·307	0·673
MAY 21								
	Fine and sunny all day							
	Grass very wet	*Very wet*	*Almost free of external moisture*		*Dry*			
Yield of fresh herbage	345	307	223	233	225	..	..	..
Yield of dry matter	62·5	57·1	48·2	52·2	51·1	4·55	0·215	0·673
Yield of nitrogen	1·77	1·62	1·20	1·39	1·40	0·122	0·588	0·673
Percentage of water in fresh herbage	81·7	81·4	78·2	77·5	77·3	0·407	1·671	0·673
Water ratio	4·46	4·38	3·59	3·44	3·41	..	..	..
Percentage of nitrogen in dry matter	2·82	2·84	2·50	2·67	2·74	0·064	0·751	0·673

Constituent	Time of cutting. Weather and grass conditions*						Standard error	Value of Z	
	9.30 a.m.	11 a.m.	12.30 p.m.	2 p.m.	3.30 p.m.	5 p.m.		Found	Fisher's table ($P = 0·05$)
JUNE 28									
	Warm and sunny all day								
	Grass wet with dew	*Appreciably drier*	*Almost free of external moisture except for patches at base*						
Yield of fresh herbage	300	268	297	313	269	293	..	..	..
Yield of dry matter	56·2	54·4	62·4	64·9	58·6	62·6	3·26	0·229	0·601
Yield of nitrogen	1·11	1·05	1·15	1·25	1·08	1·22	0·082	Not significant†	..
Percentage of water in fresh herbage	81·3	79·6	78·9	79·3	78·2	78·6	0·505	0·763	0·601
Water ratio	4·35	3·90	3·74	3·83	3·59	3·67	..	..	..
Percentage of nitrogen in dry matter	1·98	1·92	1·84	1·92	1·84	1·95	0·074	Not significant	..
OCTOBER 9									
	Dull and windy				*Drizzle*	*Rain*			
	Grass very wet	*Wet*	*Much drier*	*Dry*	*Wet*	*Very wet*			
Yield of fresh herbage	286	177	147	142	232	235	..	..	..
Yield of dry matter	46·4	33·0	30·4	32·8	43·8	38·8	3·59	0·598	0·601
Yield of nitrogen	1·14	0·83	0·72	0·74	1·01	0·88	0·090	0·588	0·601
Percentage of water in fresh herbage	83·7	81·3	79·2	76·5	81·1	83·5	0·814	1·203	0·601
Water ratio	5·14	4·35	3·81	3·26	4·29	5·06	..	..	..
Percentage of nitrogen in dry matter	2·43	2·51	2·39	2·26	2·34	2·28	0·117	Not significant	..
OCTOBER 11									
	Fine and sunny			*Light shower at 1.45 p.m.*	*Fine and sunny*				
	Slight external moisture in patches at base			*Grass slightly wet*	*Dry*	*Becoming damp with dew*			
Yield of fresh herbage	147	202‡	168	130	141	167	..	..	..
Yield of dry matter	31·7	42·7‡	36·1	31·6	32·5	35·9	2·68	0·458	0·601
Yield of nitrogen	0·79	1·05‡	0·91	0·75	0·78	0·87	0·070	0·456	0·601
Percentage of water in fresh herbage	78·4	78·7	78·2	75·6	76·9	78·4	0·905	0·298	0·601
Water ratio	3·63	3·70	3·59	3·10	3·33	3·63	..	..	..
Percentage of nitrogen in dry matter	2·51	2·45	2·49	2·36	2·41	2·43	0·104	Not significant	..

* Weather conditions during intervals between cuts. Notes on the condition of the grass, indicating the presence or absence of external moisture and its approximate extent.
† Owing to the continued heavy rain it was not possible to obtain accurate yields.
‡ High values due mainly to an abnormally high yield from one of the three replicate plots.

MECHANIZATION IN BRITISH FARMING

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THE term 'mechanization', in connexion with British farming, was first used to describe the specialized cereal farms which came into being about six years ago. These farms flouted tradition first by operating, sometimes in districts wedded to strictly orthodox systems of farming, on a simple rotation of one or two cereal crops followed by a bare fallow; and, secondly, by making such extensive use of tractors, combine-harvesters, and wide cultivating implements that regular labour requirements were reduced to something like one man per 250 acres. As a result, the costs of cereal-growing were reduced to rather less than £5 per acre for a four-quarter crop, and, since wheat, the crop mainly grown, was subsidized, a profit was assured so long as the land could be kept in good heart by mechanical working and chemical fertilizers alone. This was mechanization in its strictest sense, for on these farms labour-saving machines and methods adopted *en bloc* from overseas controlled the whole system: everything else was modified or eliminated to suit the machine's requirements.

Whether it is possible, or even desirable, for this type of farming to be widely practised in Great Britain need not be discussed, since at the moment hardly any farms retain it in its original form. In nearly every case specialist farmers have introduced one or other form of live stock or an alternative field crop just as soon as there has been any prospect of their being able to do so profitably. At the same time, even the most ardent opponents of specialized cereal-growing could not disregard the economies that had been effected, partly by the use of mechanical power, and partly by concentrating on a limited range of products. The result has been the rapid evolution in Great Britain of a system which, since it depends very largely on the use of mechanized power, is still called mechanized farming but which, because it may also involve many changes not directly concerned with machines, might be described more accurately as rationalized farming. Since it has derived partly from an extension of activities by specialist farmers, partly from the adaptation of some of their methods by more orthodox arable farmers, and partly from the invention of new methods applicable to particular circumstances, the ramifications of mechanized farming in its newer sense are very wide. There is, in fact, no such thing in Great Britain as a typical mechanized farm. But certain general features, applicable in a greater or lesser degree to all the farms which have any claim to be regarded as mechanized, can be recognized. Among them are:

1. The replacement of horses by tractors whenever by so doing the output per man can be increased.
2. The elimination as far as possible of unnecessary or unprofitable operations. Two typical examples, one involving machines the other not, are the elimination of stooking and stacking by the use

of the combine-harvester, and the elimination of manure-carting by the use of folding-systems of pig- and poultry-keeping.

3. The modification of farm rotations, not by departing altogether from orthodox methods, but by concentrating on those crops whose production costs can most easily be lowered or on those which will give an immediate cash return. In either case, each product must be prepared to stand on its own legs. An arable crop which requires dung must be prepared to pay all the costs of preparing and hauling it; and if the live stock needs straw the same principle must apply.

The mechanization of mixed farming on these lines was the subject of a Conference at Oxford earlier in the year, and in the published Proceedings [1] are included several accounts of the working of individual farms. It is not proposed here to discuss these or any other particular farm, but only to give a general account of the new methods used in some of the more important farming operations.

Tractors and Power Cultivation

Broadly speaking, the tractors commonly used on mechanized farms in this country fall into three classes: track-laying tractors of from 18 to 25 drawbar horse-power; standard type wheel-tractors generally from 10 to 15 d.b. h.p. but sometimes larger; and general-purpose wheel-tractors in a variety of sizes usually not exceeding 15 d.b. h.p. Practically all the original specialized farms relied for their main source of power on track-laying tractors capable on average land of pulling a four- or five-furrow plough. Track-layers were regarded as essential because of a fear that spring cultivations might be delayed by the land being unfit for wheeled machines early in the year. More recently it has been realized that although wheeled tractors may not be able to work the land as early as horses could, they have little difficulty in making up for lost time once the land is fit. And so, although track-layers are still popular on the original mechanized farms, there is a tendency for newcomers to mechanization to favour wheeled tractors on account of their lower rates of depreciation. The size of the main power-unit has, in most cases, been decided on the one hand by the need for a machine powerful enough to pull a standard combine-harvester at the reduced speed which heavy long-strawed crops require, and on the other hand by the difficulty of providing a sufficient load for a really large machine. In ploughing some of the lighter lands even a 20 h.p. tractor requires seven or eight furrows for a full load, and two ploughs coupled together are occasionally used. But for the most part ploughing is done by single-unit implements of four or five furrows, and tractors of more than 25 h.p. are not at all common.

Lower-powered wheeled tractors are used on nearly every farm for odd jobs: haulage both of seed and fertilizers at sowing-time and of crops at harvest-time; light work such as mowing and harrowing; and in a few cases where ploughing is done in 'lands', for setting out the work. Increasing numbers of these tractors are being fitted with pneumatic tyres to facilitate haulage, particularly where public roads must be traversed—

as is commonly the case on British farms—and to allow higher working-speeds to be used on occasion. General-purpose or row-crop tractors are being used to bring potatoes, sugar-beet, and certain vegetable crops into the range of mechanizable products. British farmers do not like implements built on to or around their tractors, so standard American row-crop equipment is hardly ever seen in this country. As an alternative, various British-made row-crop units are available and can be provided with attachments for carrying out most kinds of row-cultivation. These units have developed from the old steerage horse-hoe and, although directly attached to the tractor, are placed behind it on their own wheels, so that they can be removed or replaced very quickly. They require two men to work them, a tractor-driver and a man steering the hoes or cultivators, and are generally capable of covering a working width of about 9 feet.

Most of the other cultivating implements used do not differ appreciably except in size from those used on ordinary farms. An exception is the disk plough, which was never used with horses in this country, but which is becoming increasingly popular as a tractor-implement. There is some difference of opinion in regard to ordinary disk ploughs, although there is little doubt that they will reproduce on some land the work of digger-breast mould-board ploughs with a considerably reduced cost of maintenance. The so-called one-way or poly-disk ploughs are generally recognized as efficient implements for stubble-breaking, cross-ploughing, particularly in fallow-making, and for seed-bed preparation.

Fuller details of the cultivating methods practised on mechanized farms are given in a bulletin by Newman [2]. As this brief review indicates, however, very little in the way of spectacular equipment is used. Rotary cultivators and similar devices are uncommon and the gyrotiller —a giant machine which might well be taken as a symbol of mechanization—actually plays little part in the system. The machine is too large to be generally used except on contract work; and mechanized farming of the kind under consideration is essentially a matter of farming with one's own equipment.

The Corn Harvest

The working of the specialist cereal farms was based on the use of the combine-harvester; indeed, the successful demonstration of the machine under British conditions in 1928 and 1929 led immediately to the development of these farms. Judged by direct results the combine-harvester has been completely successful in this country. On account of the greater bulk of our crops the cutter-bars of standard American machines had to be reduced in width, generally to 12 ft.: whilst the vagaries of our climate made the provision of grain-drying equipment essential. With these modifications the new method reduced grain-harvesting costs by about £1 per acre by comparison with ordinary methods of working with horse-drawn binders, and, at the same time, greatly reduced the risk of damage by unfavourable weather. In recent years, however, the combine has hardly made as much progress as might have been anticipated, and in 1935—the sixth year of its use on

commercial farms—there were, excluding a few demonstration and contract machines, only 41 actually at work in Great Britain. The work of these machines and the organization of some of the 31 farms employing them have been described by Bridges and Whitby [3].

Where combines are not used harvest-mechanization has consisted only in the use of wide-cut tractor-binders and in a gradual extension of the practice of threshing from the field without intermediate stacking. In the absence of detailed costs of the latter method, it is difficult to judge whether it is appreciably more expensive than 'combining'. In any case the answer will depend on the value placed on the straw which combine-users generally plough in or burn. On one well-known mechanized farm as much straw as possible is being collected behind the combine, and is sold by the cereal department to the live-stock branch —an indoor pig herd—at £1 per ton. Quite apart from whether the straw is worth as much as this to the pigs, a value of £1 per ton would appear to make the overall economy of the combine-harvester rather doubtful. Some farmers consider that combine-harvesting has other disadvantages: the grain must be marketed immediately unless expensive storage accommodation is provided; and weed seeds are broadcast over the stubbles. The first of these, of course, would apply equally well to any method of threshing direct in or from the field. The second may, in the long run, prove serious. On the whole, whilst it is certain that more combines will be used, it is doubtful whether the machine will ever become universal unless the new continental machines, which aim both at threshing the grain and binding the straw, and which are being made on a scale more appropriate to our small fields, are successful. The grain-drier, however, is likely to become a permanent feature of our countryside, for its advantages in our uncertain climate are quite definite.

Haymaking and Grass Conservation

Mechanization of haymaking has consisted simply of the speeding-up of cutting by means of tractor-mowers, and of carrying by means of hay-sweeps, or loaders and mechanically hauled wagons. The ability of the tractor-mower to cut some 25 acres per day—as against 8 or 10 acres with a two-horse machine—allows cutting to be delayed until a spell of fine weather has set in, and so makes haymaking easier from the start. But the greater advantages of mechanization are realized when the hay is made and needs only to be gathered in as quickly as possible. Whatever actual method of collection is used, the tractor saves valuable time because of its greater travelling speed. For sheer speed of working, however, motor sweep-rakes attached to the front of second-hand high-powered cars and used in conjunction with an overshot stacker are superior to anything else. According to an article in an earlier number of this *Journal* [4], three motor-sweeps and a stacker raise the output of a team of workers to something like three times what they could do by hand-forking into horse-drawn wagons. This method cannot be used where it is inconvenient to stack the hay in the field, nor is it so effective where the land is set up in steep 'ridges'.

The article referred to above [4] also describes the working of an American

'pick-up baler'—the equivalent in haymaking of the combine-harvester—which was tried out in this country in 1932 and 1933. The machine worked reasonably well, but on account of its high cost and relative slowness made no appeal to our farmers. There is, on the other hand, an increasing tendency to use motor-sweeps in conjunction with a stationary baler in the field. The hay can be taken at once for storage elsewhere, the cost of subsequent cutting-out is avoided, and there is a possibility that a better product can be made, since it appears that hay can be baled in rather greener condition than that in which it would be safe in a stack. On the whole, mechanized haymaking aims at minimizing weather risks rather than lowering costs. The newest method of all—artificial drying—aims at eliminating the weather altogether. Attempts at drying hay artificially have failed in the past mainly because in a good season drying has been unnecessary, and in a bad one the process has cost more than the value of the final product. Recent work on the feeding-value of dried young grass, however, has put artificial drying in a different perspective. The final product produced by modern drying-plants is not hay but a much more valuable one: dried young grass with all its original properties unimpaired. The process is fully described in both its theoretical and practical aspects in the Conference Proceedings already mentioned. At the moment the plant is expensive, and the process available only to large-scale farmers; but this is likely to be altered in the near future.

Efficient methods of collecting the cut material have already been developed; and the fact that it costs no more to dry good grass than bad has given an added stimulus to grassland cultivation.

Mechanization and Mixed Farming

With a few exceptions, of which the most important is the milking-machine, mechanical appliances cannot be applied directly to reduce the costs of live-stock husbandry. In consequence, mechanization in mixed farming is concerned mainly with so rearranging the system that the economies which the methods already discussed can effect in crop-production are not lost when the crops concerned have to be fed to stock on the farm. This is very largely a matter of transport: either of making transport more efficient or of eliminating it altogether. An extreme example is provided by Mr. Hosier's system of which a full account has been given by Orwin [5]. It is a system of alternate grass and arable husbandry arranged so that hay and straw are used near where they have grown, and all the live stock is folded on, or ranges over, the grassland. There is, thus, no dung-carting, and very little haulage of feeding-stuffs. In this particular case milk is the primary product, and an ingenious portable milking-shed is a feature of the system. Methods, similar in principle, are, however, being more widely used every year with poultry, pigs, and even fattening cattle; but since they all involve out-wintering stock they are necessarily confined to land which will stand treading under wet conditions.

On other types of land mechanized live-stock production depends on making the best use of pneumatic-tyred tractors and trailers, and on adapting yards and buildings to facilitate loading and unloading. The

extent to which mixed farming will be mechanized in the future depends very largely on whether our farms can be reorganized into rather bigger units than are common at present. Both because the size of some of the machines concerned is being reduced and because there is a growing appreciation of the fact that, in general, equipment wears out only in proportion to the amount it is used, prevailing estimates of the limiting acreage which can be economically mechanized are gradually being lowered. The process cannot, however, go on indefinitely, and sooner or later it must appear that farms smaller than, say, 300 acres are definitely uneconomic, at any rate for corn and hay, whether they are to be fed on the farm or not. On the other hand, it is doubtful whether mechanization need involve very large farms for, on the practical evidence now available, it would not appear that there is much to be gained by the mere multiplication of working-units.

Apart from such questions of the size of unit, there would appear to be no limits to the spread of mechanization. It is true that few of the farms so far mechanized are situated on the heavier soils, but this is due mainly to the fact that in Great Britain large farms tend to be associated with light land. Mechanization of heavier land may mean using more track-laying tractors and will certainly involve higher working-costs, but there should be heavier crops by way of compensation. It is also true that the labour requirements of some crops cannot be reduced very much, even by mechanization. But these crops are the exception rather than the rule and various ways of doing without them are being worked out. Perhaps the most far-reaching development of all, and the one which will influence the spread of mechanization more than anything else, is artificial grass-drying. The greater part of the country is devoted to grassland and at present depends for its concentrated winter food-stuffs on sources outside agriculture. If these concentrates can be provided on the farm in the form of dried grass, enormous possibilities are opened up, and a more general system of alternate husbandry is likely to result.

Short- or medium-term leys devoted partly to grazing and partly to the making of dried grass will increase the productivity of what is now permanent grassland, enable fertility and humus-content to be cheaply maintained, and, enable the benefits of mechanization to be fully realized.

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EMPIRE SUGAR

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THE Chadbourne Plan was an attempt to reduce the unsaleable stocks of sugar in the world, and, by restoring a healthy balance of supply and demand, to raise world prices to an economic level. Owing largely to the United States and the countries of the British Empire not being parties to the Convention, and to the growing economic nationalism which narrowed the unprotected 'free' market, these aims were not fully realized. Sugar stocks were indeed, reduced; but prices remained and still remain obstinately low. The Convention was allowed to lapse at the end of the five years agreed upon. The hope of rationalizing the supply and distribution of sugar in the world now rests on the outcome of an International Sugar Conference, at which all the countries concerned are to be represented, which it is proposed should be convened at an appropriate moment by the Government of the United Kingdom. Preliminary discussions have been carried to an advanced stage, and though it is still uncertain whether, in view of recent Supreme Court decisions regarding agricultural policy, the United States are yet ready to participate, the prospects of the Conference are hopeful. The discussions at such an International Conference could not fail to have a profound influence on the relations between producing and consuming countries generally, and hence upon the relations of the sugar-surplus countries of the Empire with their preferential markets in Great Britain and Canada.

The following notes summarize the situation as it appears in the various sugar-producing regions of the Empire, on the eve of the suggested International Conference, the countries being taken in geographical order from Fiji in the east to British Guiana in the west. They are naturally concerned in the main with the producers of cane sugar, whose almost universal dilemma is the necessary increase of production for technical and economic reasons, while the scope of the market available for them is inevitably limited. From the present point of view the problems of the beet-sugar industries in the temperate Empire countries are relatively unimportant, and they have not been discussed. Except in so far as the recent settlement of the U.K. beet-sugar industry tends to simplify eventual negotiations, its details are rather of local significance, and they have consequently been omitted.

Fiji

Like other sugar-growing countries in the Empire, Fiji shows a strong tendency to increase production above the pre-War level:

TABLE I. *Production of Sugar in Fiji*

Year	*Tons*	*Year*	*Tons*
1913–14	92,112	1933–4	116,113
1931–2	79,725	1934–5	112,806
1932–3	135,241	1935–6 (estimate)	127,000

The crop is grown for export and manufacture is in the hands of the Colonial Sugar Refining Company, Ltd., the largest of the Australian sugar firms. Rather more than half the exports go to Great Britain and rather less than half to Canada. Up to a few years ago, Canada was the chief market. Nearly the whole of the export to Great Britain consists of the Colony's quota (44,000 tons) for the special preference granted to Empire sugar. The continued low price of sugar makes it necessary for exports to be sent to preferential markets. The crop is produced by peasant farmers, the estate system having become unsatisfactory since immigration from India ceased in 1916. Over three-quarters of the cane is produced by Indians, but the quantity grown by Fijians is increasing. Research into fertilizers, biological control of insect pests, and cultivation practices have been carried on by the Company's Officers for many years. New varieties of cane are tested for suitability to the soils and climates of various districts.

Fiji is capable of expanding its sugar output, but is restrained by the unremunerative level of world prices. Indeed, if the value of receipts were to fall further, the Company might be tempted to give up its Fijian interests altogether. As sugar is the mainstay of the island agriculture, the maintenance of at least the present value of the industry is of the greatest importance.

Australia (Queensland)

Apart from an annual production of about 30,000 t. of cane sugar in New South Wales and about 5,000 t. of beet sugar in Victoria, the Australian sugar crop is grown in Queensland. The progress of the Queensland sugar industry may be summarized as follows:

TABLE 2. *Production of Sugar in Queensland*

Year	*1,000 acres harvested*	*1,000 t. cane yielded*	*1,000 t. raw sugar produced*	*Tons of sugar per acre*	*Tons of cane to 1 ton of sugar*
1900	73	848	93	1·27	9·17
1914	108	1,923	226	2·09	8·51
1925	189	3,668	486	2·56	7·55
1926	189	2,953	389	2·06	7·59
1927	204	3,556	486	2·38	7·32
1928	216	3,736	521	2·41	7·18
1929	215	3,581	519	2·41	6·91
1930	222	3,529	517	2·33	6·83
1931	233	4,034	581	2·49	6·94
1932	205	3,546	514	2·51	6·90
1933	228	4,667	639	2·80	7·31
1934	218	4,270	613	2·80	6·97
1935*	..	4,190	605	..	6·93

* Estimates.

These figures show that the scope of the sugar industry in Queensland was practically trebled during the first 30 years of this century. The yield of cane has fluctuated, owing largely to the vagaries of climate, but

that of sugar has increased fairly steadily, from 1·27 t. per acre in 1900 to 2·56 t. in 1925, and 2·80 t. in 1933 and 1934. Improved field practice and mill efficiency, the greater use of irrigation, better knowledge and application of fertilizers, the more general planting of disease-resistant and high-yielding cane, all tend to increase the average production of sugar per acre and, on the whole, to bring down overhead costs, unless the grower's output falls below a certain minimum, which must increase as the value of sugar falls.

In too many cases, this economic minimum output is not being attained. Sugar is the chief field crop of tropical Queensland, the population of which has more than doubled since the War—between 1921 and 1933 it increased from 45,000 to 97,000. Sugar occupies 20 per cent. of the cultivated land, and sugar-cane accounts for 60 per cent. of the value of agricultural production and 20 per cent. of all the commodities produced. The number of immigrant growers is increasing, and provision must also be made for members of the farmers' families, but no more Government land is available for starting new farms. Hence the average size of the holding tends to diminish faster than the average yield increases, so that average production falls. The grower is bound to deliver all his cane to a particular mill and no mill is allowed to exceed its previous 'peak year' output. As the number of growers in a given district increases, the quota of each farmer supplying the mill must fall.

The total output which can be divided among the mills is limited by the size of Australian consumption and the amount that can be exported. The home market is reserved for Australian sugar and absorbs about 320,000 t., or 60 per cent. of the output, the official price being well above the world-market level. The remaining 40 per cent. is exported, chiefly to Great Britain and Canada, where it enjoys preferential treatment under existing trade agreements. The British rebate of 3*s*. 9*d*. per cwt. will continue, under the Ottawa Agreement, till August 1937.

The central problem from the Australian point of view is the disposal of excess sugar, and it is important that the existing demand should be maintained and if possible increased. Growers would doubtless prefer a moderate sacrifice of output in addition to the restriction which they have accepted since 1930 under the 'peak year' scheme to the ruinous competition with which they are faced.

At the end of 1935, the Federal Parliament passed the Sugar Agreement Bill, which continues the embargo on imports and the fixed-price system in Australia for another five years. The general effect is to stabilize conditions over a reasonably long period, in so far as purely Australian action can do so, and to keep sugar production well under control. The hand of the Commonwealth Government will thus be strengthened for future discussions with the United Kingdom and in any International Sugar Conference that may be called.

In Australia, as in so many Empire countries, technical advances are making for increased production, whilst economic considerations set a higher limit to the total output and a lower limit to the crop of the individual farmer. The problem is one of resolving the apparent contradictions of these tendencies.

India

By far the greater part of Indian production consists of *gur* or *jaggery*, an imperfectly refined form of sugar for local consumption. A small proportion of this is used for making white sugar, though this branch of the industry is declining, and a certain amount of low-grade white sugar is made by the open-pan or *Khandsari* process. Since 1931, modern factories for the manufacture of white sugar direct from cane have increased rapidly, under the protection of the customs tariff.

TABLE 3. *Production of Gur and White Sugar in India 1929–30 to 1935–6*

	1929–30 (*Thousand tons*)	*1934–35*	*1935–6* (*Est.*)
Gur for consumption as such . .	1,837	3,500	4,000
Khandsari	200	150	125
White Sugar refined from *gur* .	21	40	40
White Sugar made in modern factories direct from cane . . .	90	578	684

TABLE 4. *Production of White Sugar direct from Cane, 1925–6 to 1935–6*

Seasons	*Factories working*	*Cane crushed (tons)*	*White sugar produced (tons)*	*Recovery (per cent.)*
1925–6	23	659,406	52,990	8·03
1926–7	25	742,368	62,941	8·47
1927–8	26	786,476	67,684	8·60
1928–9	24	791,361	68,050	8·59
1929–30	27	989,776	89,768	9·07
1930–1	29	1,317,248	119,859	9·09
1931–2	32	1,783,499	158,581	8·89
1932–3	57	3,350,231	290,177	8·66
1933–4	112	5,157,373	453,965	8·80
1934–5	130	6,672,030	578,115	8·66
1935–6 (estimates)	140	9,780,000	885,000	9·05

The establishment of a sugar-refining industry originated in the application of scientific methods to sugar-cane problems early in the present century. The growing-season in India was short, the yield was low, the quality of cane poor, and the land-tenure system generally opposed to the formation of compact estates where the best methods could be practised. The need was for a more robust, early-ripening cane, and for a higher yield of sugar. As a result of suggestions made by the Board of Agriculture in 1911, the Coimbatore Cane-Breeding Station began its work, under the late Dr. Barber.

The outstanding services rendered by Coimbatore are probably the following:

(*a*) The discovery of the importance of the wild *Saccharum Spontaneum*, or *Kans* grass, as a parent for hybrid seedling-canes for North India, and the application of this and of the subsequent discovery of *Kassoer* cane.

(*b*) The establishment of the importance of the cane root-system and the study of this subject.

(*c*) The differentiation on the basis of root-system between 'noble' tropical canes and the native canes of sub-tropical India.

(*d*) The production of inter-generic hybrids between *Sorghum* and sugar-cane, with a view to early maturity.

It is claimed that there is now a Coimbatore variety specially suited to practically every Indian sugar area. The breeding of sugar-cane–sorghum hybrids is continued on a wide scale, and promising seedlings can now be sent to out-stations and thus tested in different climatic and other conditions. Thick or noble varieties are being bred, some to obtain types for semi-irrigated conditions and some to suit the drier regions of South India. Intensive studies in morphology and cytology and extensive soil surveys are in progress. Canes are, in general, being bred to increase their resistance to disease, to secure the erect habit of growth, and to develop rind hardness as a protection against insects and rats.

In 1911, the yield of cane per acre was about 10 t.; the sugar-content was about 6 per cent.; mature canes, fit for crushing, were available for about 70 days in the season; the area under canes was 2,215,000 acres; the yield of *gur* 2,218,000 t., that of sugar under 15,000 t. Hardy varieties of cane, with hard rinds, resistant to insects and to mosaic disease, and thus suitable for improved yields under village conditions, are now common. The area under cane amounts to about 4,000,000 acres; yields are from 20 to 35 or more tons per acre: recovery is at the rate of 10 or more per cent. in many areas; the crushing season may last from November to April. The application of scientific methods to Indian sugar has, in fact, been successful, and the fiscal protection granted in 1931 is no more than a stage—though a most important one—in the progress of India from being a deficit to becoming a self-supporting country.

The indigenous demand for *gur* will always be satisfied from home-grown cane. In the five years 1927–31, India's annual consumption of factory sugar was about 962,000 t. The increase of consumption depends on the general prosperity of the country.

Disasters like the Bihar earthquake have retarded progress. Insect infestation in the United Provinces has caused doubts—happily not confirmed—as to the possibility of continuing the sugar crop there. These and other adverse factors, such as the uncertainty of cane supplies and the uneconomically small capacity of many mills, have slowed down the expansion of the output and the stage of complete self-sufficiency has not yet been reached. India has, however, been almost entirely withdrawn from the world market. The significant fact is that a large quantity of sugar formerly exported to India must now find other outlets or must cease to be produced. The whole structure of the world's sugar trade and in particular that of Java is thereby modified.

Mauritius

Before 1928, Mauritius was an exporter of white sugar, mainly to Great Britain. The British tariff arrangements made in that year

changed the character of the industry by greatly increasing the proportion of the crop exported in the form of raw sugar. The amount produced does not, as in so many other Empire countries, show any tendency to increase:

TABLE 5. *Production of Sugar in Mauritius (metric tons)*

Season	*Tons*	*Season*	*Tons*
1913–14	249,705	1932–3	247,220
1928–9	253,430	1933–4	261,460
1929–30	238,030	1934–5	178,860
1930–1	220,960	1935–6 (estimate)	263,000
1931–2	164,010		

The effect of the British tariff on the character of the exports is clearly shown in the percentages of raw and 'vesous' (i.e. refined) sugar, which between them account for over 98 per cent. (of recent years over 99 per cent.) of the total. From 1925 to 1927 the average percentage of sugar exported as 'vesous' was 98. From 1928 it declined to 11·8 in 1934 and 20·6 in 1935, the remainder being exported as 'raws'.

Apart from the necessity for meeting the change indicated above, Mauritius has had to contend with a succession of difficulties. Before the War, the chief adverse factor was infestation by the destructive beetle *Phytalus Smithi*, which was first discovered on sugar-canes in 1911. Action against this pest is still one of the main preoccupations. The War boom brought prosperity and this made great local improvements possible, but the post-War slump and a succession of climatic difficulties have reduced the industry to great straits. It is only this season that Mauritius begins to get the better of these cumulative disasters, by the aid of grants from Imperial funds.

A Sugar-Cane Research Station was established in 1929. The chief entomological problem is the control of *Phytalus Smithi*. Other research activities include cane-breeding, investigations on the root-system of the sugar-cane, variety yield trials, and manurial experiments.

The scientific and technical side of the industry is well in hand; its major difficulties are economic. To maintain the level of exports to the United Kingdom is of great importance from the island's point of view.

Union of South Africa

Under the stimulus of fiscal protection, the production of sugar in Natal and Zululand has been increasing since 1903, when a customs convention of all South African States discriminated against sugar from Mauritius and other oversea sources, in favour of the home industry. In the decade 1923–32, the acreage reaped in Zululand increased from 26,400 to 52,000 (97 per cent.) and that in Natal from 60,000 to 88,000 (46 per cent.). The cane crushed increased from 2·15 million tons in 1926–7 to 3·87 million tons in 1934–5. The production of sugar in recent years is shown opposite:

TABLE 6. *Production, Imports, and Exports of Sugar (short tons)*

Year	*Production*	*Net imports*	*Exports of South African produce*	*Retained available for consumption*
1925–6	239,851	6,075	70,602	175,324
1926–7	242,662	4,091	66,910	179,843
1927–8	247,273	5,292	68,978	183,587
1928–9	295,934	25,261	96,681	224,514
1929–30	298,635	15,746	123,590	190,791
1930–1	393,205	6,004	210,632	188,577
1931–2	325,933	4,154	146,977	183,110
1932–3	358,905	820	185,451	174,274
1933–4	391,173	1,226	190,811	201,588
1934–5	358,738	..	..	..
1935–6 (est.)	420,000	..	..	..

The cane usually grown is Uba, which is resistant to drought and to mosaic disease. It is, however, difficult to harvest, contains much fibre and other impurities, and has recently become liable to 'streak', a virus disease resembling mosaic. In 1926, steps were taken to clear the sugar areas of all canes liable to mosaic. Between Jan. 1927 and Dec. 1930, the growing of canes other than Uba (except in quarantine) was prohibited, the object being not so much to encourage Uba as to make way for the introduction of better varieties not subject to mosaic or streak. Successive releases of Java and Coimbatore canes have been made from the Experimental Station of the South African Sugar Association, which is supported by the industry without Government funds. The new varieties can yield 180 t. of cane and 2 t. of sugar per acre. The two local enemies of the crop are drought and locusts.

As in Australia, the danger of over-production is the chief economic problem of the industry. The steps taken to deal with it also resemble those taken to deal with a similar danger in Australia. The situation had become acute by 1934, when the Minister of Commerce and Industries started an inquiry into the working of the sugar industry. In Sept. 1935 a Conference was summoned by the Minister to consider the results of his inquiry, and a Committee was set up to consider schemes for improvement. The discussions were inconclusive and a special Conference was called at Durban in March 1936 to evolve a definite scheme, failing which the Government was prepared to take control of the industry. The outcome was the Fahey Conference Agreement, which lays down the lines of future policy. Its main provisions include the limitation of total production to 476,488 t. annually, the establishment of a Central Board of Control and an equalization fund, and the unification of growing and refining in a single industry.

In fixing the amount of total production, the Conference had in mind both the requirements of the South African market, and the possibility that, as the result of the impending International Sugar Conference, South Africa's quota for export to Great Britain might not exceed 224,000 short tons. Certain millers and cane-growers claimed the right to expand their output to an 'economic' figure, a demand which again

recalls Australia. The Conference fixed maximum production at the probable South African consumption five years hence. The quotas of individual mills on this basis will be brought into conformity with market requirements by *pro rata* reductions each year. The simplification and control attained by this measure will tend to strengthen the hands of the Union Government in the coming discussions.

British Tropical America

The outstanding fact about the British West Indies and British Guiana is the steady increase of production, due in great measure to the improved varieties of cane and the better field and mill practices resulting from scientific progress. In the last quarter of a century, production in the region as a whole, which was not affected by the Chadbourne Scheme, has practically doubled, in spite of adverse conditions. In some islands (e.g. Barbados, St. Kitts) the output has been trebled, although the area under cane has changed little. In Jamaica the crop has increased fivefold. Even if the economic incentives had been the same, such a striking expansion would scarcely have been possible, unless a great advance in sugar-cane technique had been made. Pre-War results are compared with the most recent estimates in the following summary table:

TABLE 7. *Production in British Tropical America (tons)*

	*1935–6**	*1934–5*	*1933–4*	*1913–14*
Trinidad	131,000	117,786	105,342	55,488
Barbados	100,000	46,412	82,934	33,387
Jamaica	85,000	76,753	72,528	15,583
Antigua	21,000	17,700	20,677	15,345
St. Kitts	25,000	28,491	28,262	8,655
Other B.W.I.	8,000	9,175	6,730	7,799
Total, B.W.I.	370,000	296,317	316,473	136,257
British Guiana	130,000	125,000	132,240	106,211
Grand total, British Tropical America	500,000	421,317	448,713	242,468

* Estimates.

After the reorganization of the Barbados Department of Agriculture in 1925, it was possible to apply on a larger scale recent knowledge and technique, and to rely more and more on deliberate rather than on fortuitous crosses. Other West Indian Islands had not made the same progress, but the new varieties of Barbados canes selected for the very diverse local conditions by trial and error were in great demand. By 1930, over 77,500 acres had been planted with Barbados canes, in addition to 35,000 acres in Barbados itself. At the Imperial Sugar-cane Research Conference in 1931, proposals were made for the planned breeding of canes, specially suited for the needs of the separate islands, and the British West Indies Central Sugar-cane Breeding Station was accordingly established in Barbados in 1932.

Investigations into fertilizers and into the biological control of insect

pests are associated with the introduction of more suitable canes. Trinidad may be quoted as an example of the way in which the three main problems—cane-breeding, fertilizers, entomology—grow up together. The destruction caused by the froghopper insect (e.g. in 1917, when it is estimated that 10,000 t. of sugar were lost through the pest) led, in 1921, to the appointment of a special committee. They started entomological research, with which the name of Dr. Myers is associated. It was soon found that the work had to be expanded to comprise a comprehensive scheme of investigation, including soil surveys, cane ecology, and fertilizer experiments in addition. Apart from this scheme, long-term fertilizer experiments are being carried out by the Imperial College of Tropical Agriculture, in conjunction with Imperial Chemical Industries. Among the many schemes of research now in progress are those relating to cane-breeding, fertilizers, and entomology, which have been continuous in British Guiana also for many years.

The outcome of the efforts which have been and are being made is that the replacement of unsuitable by suitable canes, the better utilization of the soil, the protection of the growing crop, and the making of the final product have been systematized for the whole of this area. Yields which twenty years ago would have been regarded as distinctly good are now looked on almost as crop failures; but the market on which this greatly increased production must be sold is restricted.

In spite of the generous treatment which West Indian sugar now receives in the U.K. and Canada, its two chief markets, the continued depression of the world price reduces the value of the preference to the West Indian producer. In most of the islands, sugar is either the only crop that is grown for export or the best alternative. This goes far to explain the effort to increase production, which meets a limiting factor in the world price of sugar.

In the autumn of 1935, a delegation of the Barbados Legislature visited England, to bring to the notice of the British Government 'the precarious outlook of the only industry of importance in the island'. Sugar is the only crop grown for export, either as raw sugar or (on account of the low sugar price) as fancy molasses. The market for the latter—Canada—is, however, limited.

The population of over 1,000 per sq. mile, depending chiefly on the sugar industry, would be reduced to destitution if it collapsed. The same is broadly true of Antigua and St. Kitts. In both Jamaica and Trinidad considerable areas are still available for cane-growing, and it is probable that they will be used, since the expansion of the sugar industry seems to be essential. The Panama disease of bananas in Jamaica and the witch broom disease of cacao in Trinidad render an alternative crop an urgent necessity. In British Guiana, where conditions differ from those of the islands, the severe drought of 1934, followed by abnormal rainfall, greatly retard the increase of production; but here, too, more sugar is being produced.

The more sugar the West Indies and British Guiana produce, the more they must export to the U.K., and the greater becomes the pressure on the London terminal market, so that the price must continue low. The

main problem of British Tropical America is thus to expand the preferential market for its sugar and sugar products such as molasses and rum.

Canada

Like the United Kingdom, Canada maintains a beet-sugar industry, but draws most of her supplies from abroad. Empire countries producing cane sugar enjoy fiscal preference and contribute about 90 per cent. of the imports. The readjustment of British preferential duties in 1928 has caused the relative importance of the British West Indies and British Guiana to increase. Of 359,000 t. of Empire sugar imported in 1932, 189,000 t. came from the West Indies; of 312,000 t. imported in 1933, 129,000 t. were from the West Indies, and 185,000 out of 292,000 t. imported in 1934. In 1935, the West Indies again increased their share, whilst both British Guiana and Mauritius sent considerably more than in 1934.

The relative importance of home and imported supplies is shown below:

TABLE 8. *Canada—Home and Imported Supplies of Sugar (tons)*

Year	*Consumption of imported sugars (raw value)*	*Production of refined sugar from home-grown beet*
1930	400,098	42,243
1931	403,753	47,830
1932	368,945	58,936
1933	346,045	58,675
1934	377,987	50,894
1935	416,028	67,000

While the beet sugar industry is expanding, it provides only a small proportion of the total supply. The significance of Canada, from the standpoint of Empire sugar, is rather as a preferential market for the product of the neighbouring Colonies. Consumption is increasing, after declining for a few years, and was 10 per cent. greater in 1935 than in 1934. The demand for Colonial raw sugar may, accordingly, be expected to increase also.

United Kingdom

Besides providing a market for the greater part of the raw sugar exported from Empire countries, the U.K. is itself a considerable producer of beet sugar. British supplies of raw sugar are drawn from all the chief producing countries and the London terminal market practically determines the price of non-protected sugar and hence the world sugar price, upon which the various preferential prices are based. The capacity of the British market to absorb the surplus sugar of Empire countries is limited by the trend of consumption in the U.K., the needs of the refiners beyond the level of immediate consumption, the size of the home beet-sugar crop, and the amount drawn from non-Empire sources.

Since the War, a beet-sugar industry has been built up in England and Scotland with the aid of a subsidy. After prolonged discussions, the eighteen factories refining beet-sugar have been brought together, under the Sugar Industry (Reorganization) Bill, into a Corporation,

somewhat like a public utility company. A Sugar Commission has been appointed to act as an administrative body, interposed between the Corporation and the growers of sugar-beet. The total area for beet-growing contracts is to be determined each year by the Commission, in such a way as to limit the production of white sugar to 560,000 t.

The part played by home-grown beet sugar in the building up of supplies for British consumption is shown in the following comparison:

TABLE 9. *U.K. Consumption of Imported and Home-grown Sugar (Raw Value). (Tons)*

	Imported	*Home-grown*	*Total*
1935	*(1,604,678)	*(611,092)	2,215,770
1934	1,653,616	545,080	2,198,696
1933	1,673,289	421,428	2,094,717
1932	1,819,164	277,992	2,097,156
1931	1,811,281	405,797	2,217,078
1930	1,728,318	382,563	2,110,881
1929	1,775,219	251,171	2,026,390
1928	1,811,223	199,202	2,010,425

* Provisional.

In the past seven years, the total consumption of sugar in the U.K. has risen by 200,000 t., but that of home-produced beet has in the same period risen by over 300,000 t., so that the market for imported sugar has been, on balance, restricted. If consumption continues to expand, the stabilization of the home beet-output will cause a corresponding expansion of the demand for imports. Part of this demand will be met from foreign sources, the remainder from Empire countries. The elasticity of this part of the British demand is a measure of the extent to which the output of Empire producers can safely be increased.

Under the 1926 Finance Act, the preferential duties on Empire sugar were stabilized for a period of ten years. This period has been provisionally extended till August 17, 1937. In 1934, modifications were introduced into the preference for Colonial sugar, whereby a special reduction of duty amounting to 3*s.* per cwt. was granted on an annual total of 360,000 t., which was divided among the colonies concerned by a system of quotas. The preferences granted to S. Africa and Queensland were fixed for a period of five years under the Ottawa agreement. These agreements end on August 17 and June 30, 1937, respectively.

All Empire suppliers aim, naturally, at making sure of their quotas in any new agreement that may result from the proposed International Sugar Conference. The settlement regarding the beet-sugar industry frees the hands of the United Kingdom to some extent for negotiations at an eventual conference. The impending termination of the present Empire preferences at much the same date frees them still more; and the relations of the sugar-exporting Empire countries to their customers (mainly the U.K.) are thereby put in a better way of being stabilized on a fresh basis.

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RECENT EXPERIMENTS ON MANURING *HEVEA* AND THEIR BEARING ON ESTATE PRACTICE

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WITH PLATE 16

I. *Summary*

THE paper describes the reasons why *Hevea* plantations grow increasingly in need of nitrogenous manuring with advancing age, and why the results of changes of vigour are but slowly reflected in the yields. The earlier published results are surveyed, including the classic case of Grantham's experiments in Sumatra.

The results of a large number of experiments carried out in the last five or six years are presented and discussed, and lead to the following conclusions:

1. In mature rubber nitrogen is usually the only element required for rejuvenation by manuring. Organic forms of fertilizer have not justified their extra cost over sulphate of ammonia during the period of five years.

2. Yield-response may be rapid in rubber which has been backward, if it is still fairly young, but in old rubber response is usually slow. Two stages of recovery may be noticed, the first being associated with the quick recovery of foliage and the second with the slower improvement in bark. Expenditure may result in profitable return in from one to seven years, and during this time the capital value of a stand is much enhanced.

3. It is shown that the economic value of manuring depends not only on the arrest of deterioration, but also in bad cases upon definite movement of yields towards recovery.

4. The growth-rate of the trees provides a useful criterion for judging the degree of starvation and the frequency of application required. It is tentatively suggested that quick response is likely to be obtained where the growth-rate of the trees has fallen below a standard girth-increment of half an inch per year.

5. Young rubber on replanted sites will seldom do well without manuring, and mineral elements are required to support nitrogen. Complete fertilizers should, therefore, be given until it can be proved whether one of the mineral elements can safely be omitted.

Exceptional cases are dealt with, and comments made on outstanding questions related to manuring, such as the uses of natural undergrowth and the treatment of *Oidium* leaf-disease.

II. *Introduction*

During the earlier period of the development of *Hevea* plantations little attention was given to manuring. Virgin soils were available and the results were naturally good, whilst large profits were so easily earned

that no emphasis was laid upon refinements in methods of cultivation. At later stages, however, visible deterioration in the trees made it plain that ameliorative treatment was required, but at the same time periods of financial difficulty tended to delay action. Manuring of rubber has, therefore, not yet established itself as a general practice, at least in Malaya, though it is now widely realized to be a growing necessity for the adequate upkeep of estates.

The subject is one of many intricacies, but for a broad survey it will suffice to grasp a very few outstanding features. These are concerned firstly with soil changes and secondly with the peculiarly slow response of the trees. During the early development of the industry, clean-weeding became established as a fixed rule in cultivation, the chief reasons being ease of supervision and the fear of weed-competition, which was observed to have marked effects on the growth-rate of young trees. Under the system of clean weeding the changes in the soil followed a definite course of deterioration from clearing onwards: exposure caused the top soil to be lost by erosion; the loose physical texture and consequent good drainage to be lost by compacting; and the nitrogen cycle to be thrown out of balance by raised temperature, oxidation of humus being increased and renewal from falling debris being reduced. The most usual history has, therefore, been the satisfactory establishment of a well-grown stand of trees at first, followed by a gradual deterioration in which nitrogen starvation is the main characteristic. The well-established root-system precludes mineral deficiencies from becoming marked at later stages. The symptoms of mineral deficiency may be seen, however, on sites which were under cultivation before rubber was planted, but there the limitation has been present from the outset, leading to a special type of stunted growth which is usually known by the descriptive name 'orchard type'. A great deal of the most backward rubber in Malaya is on sites with such a history. Thus we have to consider two types of stand and their associated manuring problems, firstly, the restoration and maintenance of yields from well-grown rubber of good yield in the past but now more or less deteriorated, and, secondly, the stimulation of stunted, backward rubber of the orchard type.

It should be said in passing that replanting with high-yielding clones is in general a much more promising alternative than the manuring of old stands of trees, but the incidence of restriction regulations on replanting, not to mention the large capital cost, still enforces the consideration of rejuvenating treatments.

Although for many crops we have well-established knowledge of the benefits of manuring, it is difficult and even misleading to attempt to argue too closely from analogy when considering the manuring of rubber. The physiological functions of the latex are still only guessed at, and it is not yet possible to suggest fertilizer treatments designed specifically to stimulate the secretion and flow of latex. One difficulty in that direction is that sometimes increased flow may be observed from causes which are antagonistic rather than beneficial to the health of the tree, and it is worth while remarking that inverted behaviour of this

kind may possibly be at the bottom of much of the confusion at present unresolved in experimental results on manuring. Our consideration must, therefore, be limited to the general question of maintaining vigour with the expectation that yields will be closely related. The crop is drawn by various systems of tapping as a continuous drain on the trees with gradual excision of the bast of the bark, usually taking one-half the circumference for each 'panel'. The ultimate continuity of yield depends upon the renewal of the bark as a natural recovery from tapping, and the usual consumption of about 9 in. of bark per year allows anything up to ten years for this renewal between successive tapping cycles. It will appear from the results discussed in this paper that manuring would greatly relieve the difficulties which have led to growing conservatism about bark-consumption in recent years. But the point which we wish to bring out here above all others is the time lag which this dependence upon slow bark-renewal introduces between cause and effect when yield-changes are under consideration.

Setting aside yield-differences due to inherent character, the yield from a tree depends upon (1) the vigour of the tree, and particularly the depth and extensiveness of the root-system—a factor which might be loosely referred to as sap-pressure; (2) the quality of the bark under tapping, and (3) the height of the tapping-cut above the roots and its position in relation to the boundary scars of previous tapping panels. Under starved conditions the first factor may be affected by the reduced transpiration due to sparseness of leaf, whilst the second factor is affected by the poor bark-renewal, giving rise to thin hard bark, the unevenness of which is much increased by the greater incidence of cambial wounding and callous-formation. A stand of trees will sometimes become so static in growth that the normal girth-increment (which should go on regularly during the whole life of the tree) is hardly measurable over a period of years. The normal growth for untapped trees with plenty of space is over 2 in. per annum. Trees on plantations will commonly slow down to a rate of $\frac{3}{4}$ in. or less as a result of the inevitable crowding and of the drain on vigour and restrictions on sap-movement due to tapping. The renewal of bark if growth stops becomes purely a wound recovery, whereas normally the renewal depends very much on the processes of girth-expansion. This wound-recovery is most active during the first months after tapping. It is, therefore, clear that the condition of a particular region of bark under tapping, which has during its renewal integrated the changes of growth over a period of perhaps eight years, will depend largely upon the nutritional status ruling long before. Hence there is a great lag between the beginning of starvation and its final result in diminishing yields. This fact, more than any other, has caused the prevalent delay in taking the necessary action by manuring. It dominates the situation not only by presenting cases where deterioration is advanced before action is taken, but also by delaying the full manifestation of yield-benefits until long after the trees have been themselves improved by the application of fertilizers. For this reason experiments need to be conducted over the period of a full tapping-cycle before the complete story can be

unfolded, and much promising work has been prematurely abandoned for lack of early result.

III. *Survey of Earlier Results*

The classic example of rubber manuring is the well-known experiment of Grantham on the H.A.P.M. estates of Sumatra [1, 2, 3, 4]. When the last returns were published this experiment had been running for 13 years. Since it provides the longest and most complete set of published data available and affords a good illustration of general points the main results are tabulated below in Table 1.

Grantham's Experiment on White Soil

The experiment began in March 1919 on an area of young mature rubber just 8 years old. The soil was a white loam peculiar to the east coast of Sumatra and known to be particularly poor in plant-food. On this type of soil the general experience had been that rubber grew well for the first 5 or 6 years, but that then rapid deterioration set in. The experiment was laid out on ¾-acre plots arranged as a 'chessboard' with 8 replications of each treatment, 5 series of plots with different manurial treatments being included. Two of the treatments (B and D) were not absolutely consistent during the first few years, but the other three remained almost unchanged throughout the course of the experiment. These were A = Control, C = 5 lb. per tree of nitrate of soda (1·75 lb. N) annually, and E = 4 lb. per tree of sulphate of ammonia (0·82 lb. N) biennially. Later on, the two remaining series were brought into a regular manuring scheme, B = the full dressing of sulphate of ammonia (4 lb. per tree) annually, and D = half-dressings of sulphate of ammonia biennially. Preliminary experiments had shown that nitrogen was by far the most important demand, and this was borne out by the earlier results from series B and D where the addition of phosphate ('ammophos' and superphosphate) and lime (calcium cyanamide) did not in any way enhance the effect of nitrogen alone. Superphosphate actually appeared to cause a slight depression of the yield of series D in 1920. The annual yields of all five series were as follows:

TABLE 1. *Grantham's Manurial Experiment with* Hevea *on White Soil*

Age of trees	Period	Yield of dry rubber in lb. per acre[1]					Percentage comparison (Yield of control = 100)			
		A	B	C	D	E	B	C	D	E
8–9	1919–20	279 (O)	340 (N)	321 (N)	302 (N)	292 (O)	122	115	108	105
9–10	1920–21	310 (O)	398 (O)	393 (N)	325 (P)	353 (N)	128	127	105	114
10–11	1921–2	180 (O)	281 (O)	354 (N)	237 (N)	283 (O)	156	197	132	157
11–12	1922–3	298 (O)	401 (O)	533 (N)	382 (O)	465 (N)	135	179	128	156
12–13	1923–4	171 (O)	257 (O)	422 (N)	251 (N)	352 (O)	150	247	147	206
13–14	1924–5	255 (O)	346 (NP)	535 (N)	368 (O)	466 (N)	136	210	144	183
14–15	1925–6	268 (O)	356 (O)	550 (N)	392 (½N)	473 (O)	133	205	146	177
15–16	1926–7	258 (O)	354 (N)	580 (N)	392 (O)	505 (N)	137	225	152	196
16–17	1927–8	307 (O)	426 (N)	672 (N)	472 (½N)	574 (O)	139	219	154	187
17–18	1928–9	361 (O)	531 (N)	764 (N)	530 (O)	671 (N)	147	212	147	186
18–19	1929–30	358 (O)	546 (N)	757 (N)	525 (½N)	656 (O)	153	211	147	183
19–20	1930–1	334 (O)	521 (N)	709 (N)	489 (O)	608 (N)	156	212	146	182
20–21	1931–2	363 (O)	615 (N)	725 (N)	534 (½N)	611 (O)	169	200	147	168

[1] The symbol in brackets indicates the nature of the fertilizer applied each year, the unit dressing being about 0·8 lb. N per tree.

Annual dressings of nitrogen gave the quickest and best response, series C rising gradually from an initial yield of 320 lb. per acre in 1919–20 to a maximum of over 760 lb. per acre 10 years later (1928–9), at which time the control Series (A) was giving only 360 lb. per acre. The yield of Series C actually reached almost double the yield of the control in the third year and has exceeded this ratio since the fifth year. Biennial dressings of nitrogen (Series E) gave a similar though slightly smaller response, reaching a maximum of 670 lb. per acre in the tenth year. The initial level of these plots was rather below that of Series A, and from the economic point of view the experiment showed that full biennial dressings were quite sufficient, whilst half-dressings biennially (Series D) were definitely too small. The experiment did not bring out any difference between the various forms of nitrogen. The yield-level of the control has increased slightly with age (from 280 lb. per acre in 1919–20 to just over 360 lb. in 1931–2), but the appearance of the trees is reported to be deplorable with die-back in an advanced stage and exceedingly poor bark-renewal. As a result of this experiment, an expanding manurial programme was begun in 1921 on the H.A.P.M. estates and continued in 1923–6. Some 85 per cent. of the total area of these estates was situated on white soil and yielding originally 300 lb. per acre, and during this period the average yield of the estates rose steadily to about 475 lb. per acre as a result of manuring.

Grantham's first report appeared in 1924 [1] and the interest aroused by his experiment led many other people to put down manurial experiments on rubber on a number of different soil types. Many of these experiments were not so carefully planned as Grantham's, and failure to get so striking or immediate a response resulted in the premature abandonment of a great number of them. This applies particularly to Malaya, where fewer properly designed experiments were put down in the earlier years and where later the world economic crisis of 1931 caused a drastic curtailment of expenditure on all estates.

Other Manurial Experiments in Sumatra

In 1926 Schmöle [5] published a résumé of over 50 trials and experiments on estates along the east coast of Sumatra, and showed that although manuring with nitrogen gave improvement on white soils, often indicated at once by the better appearance of the trees and sometimes amounting to as much as 10–20 per cent. increase in yield in the first year, a similar response was seldom, if ever, obtained on the red soils. Most of these experiments had been continued for only a very short period at the time of the report, and thus the evidence from them was not really conclusive. Grantham himself had laid down several experiments with different fertilizers on various soil types in 1918. These experiments had been carried on for 16 months but had given little or no response within that period, with the exception of a slight increase in the yield of most of the nitrogen series during the last few months. They were not continued in view of the quicker response obtained with nitrogen on the white soils.

Manurial Experiments in Java

In 1931 van Heusden and Vollema [6] described some experiments in Java on young backward rubber and showed that whereas nitrogen alone produced practically no result, a very marked effect, both on appearance and girth-increment, was obtained with a complete fertilizer (NPK). Although the trees were already about 5 years old when the experiments were started, they were able to demonstrate that the manured trees were ready for tapping at least a year earlier than the control. Ament [7] also reported a number of experiments on young rubber which gave various results with NPK, some showing accelerated growth and others no result.

Later, in 1931, Vollema [8] made a review of the results of 58 manurial experiments on rubber in W. Java, 16 of which were on young or slow-growing rubber and 42 on mature rubber already in tapping. In the experiments on young rubber NP and NPK gave a response in all the cases in which they were included, the effect of the individual nutrients N, P, and K being positive in some cases and negative in others. Of the experiments on mature rubber N gave in 11 cases a positive result (yield-increases of 5–25 per cent.) and in 9 produced no effect. P gave small positive results (5–10 per cent. increase) in only 2 cases and K in only 1, whilst these nutrients produced no effect in 10 and 9 cases respectively. Of the 11 positive nitrogen results only 4 gave any considerable increase (15–20 per cent.) and these were on 2 types of lateritic soil. The different forms of nitrogen (sulphate of ammonia, calcium cyanamide, and nitrate of soda) all appeared to give equivalent results.

Earlier Manurial Experiments in Malaya

In 1931 Haines and Falconer Flint [9] summarized the results of 14 Malayan experiments. About half of these experiments had been carried on for 3–4 years, but the remainder for shorter periods. The results differed greatly in the various experiments and the authors concluded that, although certain general rules emerged, it would be necessary to proceed cautiously along the line of further experimentation before commercial manuring programmes could be recommended. They noted that little correlation could be discerned between soil type and response to manuring, but that where trees of poor appearance had given yield-responses, there had been obvious vegetative improvements first.

A series of reports has also been published in Malaya [10, 11, 12] giving details of a manurial experiment on young rubber carried out by the Rubber Research Institute at their experiment station. This experiment was laid out in 1928 on land cleared from virgin jungle shortly before planting, and the trees were manured from the start. The treatments included N, NP, PK, and NPK (both inorganic and in the form of cow-dung). Although cow-dung appeared to produce some initial advantage in growth-rate, no appreciable effect had been obtained with any of the fertilizers when the last set of measurements was published and the trees were approaching maturity. It appears that in this experiment reserves in the virgin soil were quite

adequate for all practical purposes and needed no assistance from outside sources.

Grantham's Experiment on Red Soil

In his second paper [2] Grantham mentioned that even on the red soils of Sumatra after the age of 12–15 years a gradual deterioration in the trees set in, not unlike that observed on the white soils, the foliage becoming perceptibly thinner and yellower, the leaves smaller, bark-renewal poorer, and yields beginning to fall off. The main differences observed on the two types of soil are that on the red soil the process takes place more gradually, and that before the vigour of the trees is exhausted they attain a better development and a higher level of yield. Accordingly, in 1926 he put down a carefully laid-out experiment consisting of four series of treatments, each with 8 replications of ¾-acre plots arranged in chessboard fashion. The treatments consisted of annual and biennial dressings of nitrate of soda, annual dressings of sulphate of ammonia, and an unmanured control. The effect of the manures was much slower than on the white soils, and yield-increases did not become appreciable till about the third year. There was no doubt, however, that the yields on the manured plots did improve steadily. The last report of this experiment gave the figures for the sixth year [4]. The relative yields of the two series treated with annual dressings of nitrogen had by then risen by just over 30 per cent. in comparison with the control, and the series treated with nitrogen biennially by about 20 per cent. On the control plots deterioration was advancing rapidly, die-back on the smaller branches being quite common and the foliage distinctly lighter in colour. The percentage increases were much smaller than those obtained on the white soils, but, as Grantham pointed out, the initial yield-level of the controls on the red soils was considerably higher when the experiment began. Grantham mentions that in 1928 an extension was added to this experiment comparing NP manures with sulphate of ammonia. After four years phosphate had shown no additional improvement over that given by nitrogen alone, though it did appear to exert a favourable influence on the growth and appearance of the trees.

An Experiment in Ceylon

There only remains to be mentioned an experiment laid out at Peradeniya Experiment Station, Ceylon, at the end of 1929 on 9–10 year-old rubber planted on the avenue system [13, 14]. This experiment consisted of 5 randomized replications of 4 treatments (annual half and full dressings of nitrogen, annual dressings of complete inorganic fertilizer, and control). The results up to the end of the fourth year are given in a recent paper [15], but are not very conclusive. The full dressing of nitrogen and the complete fertilizer appear to have given rather better yields than the control, but the differences are slight. It should be mentioned, however, that the plots of this experiment are small (only 20 trees each) and that the conditions do not appear to be

very typical. In spite of their age the trees had not been tapped prior to the commencement of the experiment.

IV. *Description of Recent Experiments on Mature Rubber*

In order to condense the large number of new experimental results available to us, we shall describe in detail only a few typical cases as well as those having special features, and give summaries of groups of experiments on uniform plans which provide grounds for certain generalizations. The most usual response is a slow and progressive one, but there are some cases of very quick returns, as well as others which show no response at all (where plant-food is sufficient in relation to other limiting factors).

1. *An Old Nitrogen Trial*

The first case to be described is chosen because it has a longer history than most and at the same time is quite typical. The rubber was of the orchard type, growing on land which had suffered a chequered history for 7 years before planting. The trees were 14 years old at the time of the first manuring in 1927 with sulphate of ammonia at the rate of 4½ lb. per tree. At the existing stand of trees this was equivalent to 2¾ cwt. per acre. The application was repeated yearly till 5 applications had been given and was then stopped. Improvement in the yield from the manured areas has been continuous to the present time, but the controls have deteriorated to a level of only 250 lb. per acre per annum. Expressing results as percentage comparisons, the manured area started at a disadvantage of 16 and steadily rose to an advantage of 22 at the end of the third year. Then followed two and a half years' resting, as the bark on the control areas was barely tappable. On re-opening in 1933 the comparison was over 50 per cent. in favour of the manured area and is remaining near this level, although no fertilizer has been applied since 1931. The change in appearance and development of the manured trees has afforded a most remarkable contrast with the control, although now after five years without manuring there are symptoms in the trees that the effect is beginning to diminish.

2. *Dunlop Nitrogen Trials*

The next series of trials is chosen because the large area covered allows perhaps the most reliable simple generalization yet available. The trials were started in 1930 on several of Dunlop's estates as a simple test of sulphate of ammonia on fields of rubber past their prime. Blocks were taken of anything between 8 and 16 tasks and half of each block retained as control, whilst half received 4 lb. of sulphate of ammonia per tree per annum, the recording of task-yields going on without disturbing estate routine. Fig. 1 represents a summary of the results from 20 such simple comparisons on three different estates, covering in all a total of 134 tasks, or over 500 acres. Two curves show the average yearly yields from control and manured areas, these being much influenced by the fact that high cuts (giving reduced yield) were predominant in the years 1933 and 1934. The trend of percentage improvement

due to manuring is also shown, giving equal weight to each of the 20 comparisons regardless of their individual differences in area. The average improvement in yield is 34 per cent. in the sixth year, but in the best cases the improvement has reached 75 per cent. Similarity between these results and Grantham's red soil experiment (p. 306) is very marked.

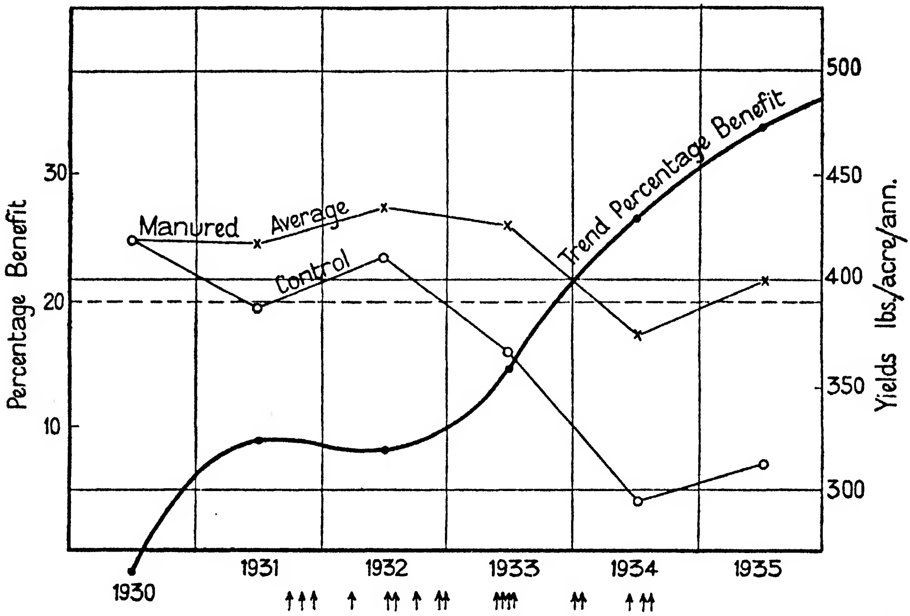

FIG. 1. Results of an extensive nitrogen trial (Dunlop's) showing in the percentage curve the two stages in which response usually occurs. Arrows show incidence of new tapping-cuts, giving reduced yields, in the different fields of the trial.

The average yield was about 350 lb. per acre per annum, and we may say that an increase of 20 per cent. of this would repay the yearly cost of the treatment (about 30*s*. per acre inclusive of labour). Drawing a cost line at 20 per cent. in the diagram we may judge the appropriate areas between this and the trend of percentage benefit and find that accumulated expenditure and return reach a balance in the seventh year, after which the extrapolated curve indicates a profit at least equal to the expenditure. The showing of other experiments is that a more conservative use of fertilizer would have given an economic balance at an earlier date. The widening difference between the yields from control and manured areas appears at first sight to be due to deterioration of the controls rather than to actual improvement of manured areas, but an analysis which was made to take into account the effect of height of cut showed an equal division of the difference, half to deterioration of controls on the one hand and half to improvement of manured areas on the other.

The curve shows two phases in the response to manuring. The main response, which we attribute to improved bark, begins to be really effective only in the fourth year, but superimposed on this is a smaller

and earlier response reaching its full in the second year and not increasing further. This we suppose to be linked with the greatly improved foliage which is noticed over the same period. Such improvement must be accompanied by improved transpiration and synthesis of those products in the tree from which latex is derived, thus giving some increase in yield through improved sap-pressure or latex-secretion, or both. It appears, however, that this particular effect quickly reaches a new equilibrium and that the fuller response in yield waits upon some slower change in the bark character. Theorizing on physiology would be out of place, but the dual character of response comes out in many cases and provokes further inquiry.

3. *I.C.I. Experiments on Mature Rubber*

The next set of results comes from the experiments under the control of Imperial Chemical Industries, Ltd. Unlike the previous experiments, in these the fertilizer was applied biennially and not annually. The general plan is a 3×3 Latin square with plots varying in size in the different experiments from 100 to 250 trees (1–3 acres) and including the following treatments: O = Control, N = Nitrogen alone (4 lb. of sulphate of ammonia per tree), and NPK = complete fertilizer (Enpekay No. 1) at a dressing calculated to give an equal quantity of nitrogen, the ratio of the other plant nutrients being, where N = 1, $P_2O_5 : K_2O = 1 : 1\frac{1}{4}$.

In 1931 altogether fifteen of these manurial experiments on mature rubber were laid out on various estates in different parts of the Malay Peninsula, but of these seven have had to be rejected as unsatisfactory. Two were abandoned prematurely by the estates concerned during the world economic crisis on the ground of economy, and it has not proved possible to obtain reliable records from the five others owing to changes in the management or other causes. Of the remaining eight, one is described under Section 5 below and the results of seven are summarized in Table 2. In this table, the actual annual yield of the control is given in each case, together with the percentage relation of the two manured series to the control. The object of this method of presenting the results is to eliminate the apparent confusion caused by violent fluctuations in some of the annual yields, due either to a long resting period (No. 3, 1932–3) or to the ABC system of tapping (No. 5), and so to give a clearer picture of the effect of manuring on yield. The increases obtained in the different experiments up to the fifth year vary from about 10 to 25 per cent.

Of the seven experiments in the summary, one gave very quick response in yield (No. 10), three gave economic response in the third year, and two in the fourth or fifth year. One (No. 2) has not yet given an economic return. In this experiment the NPK treatment has caused a certain rise in yield, but it has not yet reached an economic value. In estimating the return on manuring the comparative level of the original yields in each series prior to manuring has always been taken into account.

Experiment No. 10 was laid out on poor rubber of the orchard type

TABLE 2. *Summarized Data from I.C.I. Experiments (Mature Rubber)*

Experiment No.	2	3	5	6	8	9	10
Age (1931)	14	8	19	17	16	16	12
Stand per acre	88	100	73	57	107	85	84
Soil	Lateritic loam: Fairly good	Sandy laterite: Poor	Quartzite silt: Good	Friable sandy clay: Fairly good	Grey sandy loam: Fair	Lateritic loam: Poor	Quartzite loam: Very poor
Topography	Undulating	Mainly flat	Mainly flat	Undulating	Flat	Very hilly	Flat
History prior to planting	Cultivated	Cultivated	Cultivated	Cultivated	Cultivated	Virgin	Cultivated
YIELD-control in lb. per acre per annum (manured series as per cent. of control)	O N NPK s.e.	O N NPK s.e.	O N NPK s.e.	O N NPK s.e.	O N NPK s.e.	O N NPK s.e.	O NPK s.e.
1931	705 105 106 ..	560 93 92 ..	688 103 86 6·5	503 105 99 ..	608 115 105 ..	500 108 109 ..	454 118 2·8
1932	504 110 113 9·9	260 93 86 ..	433 101 86 ..	503 106 100 ..	601 119 107 ..	593 105 109 ..	422 124 ..
1933	410 102 108 ..	825 105 100 1·3	362 104 82 ..	496 118 113 0·7	444 125 115 ..	360 108 108 ..	412 133 ..
1934	430 103 116 4·3	681 103 102 ..	771 105 83 3·9	*Not recorded*	415 141 124 4·5	*Not recorded*	405 125 ..
1935	468 107 119 ..	850 104 94 ..	406 112 94 1·1	379 116 108 3·9	450 128 116 ..	279 134 140 3·2	324 124 2·2
ECONOMIC RESPONSE (on N treatment)	Not yet	Third year	Fifth year	Third year	Third year	Fourth–fifth year	First year

O = Control: N = Sulphate of ammonia only, 4 lb. per tree biennially: NPK = Enpekay No. 1 (12½ per cent. N, 12½ per cent. P_2O_5, 15 per cent. K_2O), 6¼ lb. per tree biennially: s.e. is the standard error of the figures in the treatment columns (which express the percentage comparison with the control).

Experiment No. 2, 1932, is five months' tapping only: rested for remaining seven months of the year.

Experiment No. 5 on 'ABC' tapping (one year's continuous tapping followed by six months' rest), causing marked fluctuation in annual yields; 1931 and 1934 are complete year's tapping; 1932, 1933 and 1935 include six months' rest.

Experiment No. 10 did not include N series, but consisted of simple trial with NPK and control (4 replications each). Though very rapid response was obtained the cost of applying a complete fertilizer is high and the return is only just economic.

Experiment No. 1 is described under section (6). Experiments Nos. 4, 7, 11, 12, 13, 14, and 15 have had to be omitted owing to premature abandonment or lack of regular records.

and gave almost immediate response, the relative yield of the manured plots increasing steadily month by month after the first manuring and then remaining on the average 25 per cent. above the control. This is the only experiment which did not include a series manured with N alone, and the increase obtained is only just sufficient to cover the cost of applying the complete fertilizer. In the other experiments, with the sole exception of No. 2, nitrogen alone has always given as good a response in yield as NPK. At a stand of 80–100 trees the cost of applying sulphate of ammonia in alternate years does not exceed 12–15*s*. per acre per annum, so that an increase of even 10 per cent. in yield may be considered profitable on average types of rubber yielding 400–500 lb. per acre.

In the majority of the experiments foliage-response was fairly rapid and in some cases became apparent during the first few months. After two or three applications the contrast in appearance between the manured plots and the control has usually become very marked, even where economic returns have not yet been obtained or are only just beginning. The denser leaf-canopy giving heavier shade, the darker colour of the foliage, and the softer, thicker, and often darker-coloured bark are most noticeable on manured areas. Measurements of bark-thickness have been made in all the above experiments and are referred to later (p. 316).

4. *Dunlop 25-Plot Experiments*

The next set of results is from the Dunlop Estates, and, providing as it does eleven cases of all kinds under one scheme of treatment, gives scope for investigating the laws governing differences in behaviour. The lay-out was designed by one of us (W. B. H.) on the assumption that nitrogen would be necessary in all cases and that the support of minerals might be of value; the possible value of an organic form of fertilizer was also tested, as most soils are deficient in humus. Each experiment includes the following five treatments in five randomized blocks, each plot providing a light task of 200 trees on alternate-day tapping: A = control; B = N, sulphate of ammonia at $5\frac{1}{2}$ lb. per tree; C = NK, sulphate of ammonia plus muriate of potash; D = NPKX, organic fertilizer (meat-meal); and E = NPK, complete inorganic fertilizer (Nitrophoska). The schedule finally worked to gave nitrogen in the following proportions B and C : D : E = 1 : 0·68 : 0·93 (with a deviation to smaller amounts in the D plots in three of the experiments).

One experiment started in 1930 and the other ten in 1931. Table 3 gives a summary of all the relevant data, all the manured plots in each experiment being averaged together, since differences between them were not significant (see Table 4) except in the one case mentioned later. Since neither the addition of minerals to nitrogen nor the use of organic fertilizer improved the results, the economic value of the response has been judged on the cost of applying nitrogen alone. Out of the 11 experiments, 4 fairly quickly gave responses which may be considered economic, 2 began to respond after 3 to 4 years, whilst 5 still fail at the fifth year to give any adequate return. Of these 5 cases, 4 were started before there was obvious need of manuring, so leaving only one case of unexplained poor response (No. 2).

TABLE 3. *Summarized Data from 25-Plot Experiments*

Experiment No.	1	2	3	4	5	6	7	8	9	10	11
Age (1931)	8	19	14	17	12	11	22	17	11	14	12
Stand per acre	100	62	100	82	78	105	71	86	85	99	100
Soil	Alluvial clay: Fairly good	Lateritic: Fairly good	Brown loam: Very good	Alluvial clay: Fairly good	White clay: Poor	Stiff clay: Fair	Stiff clay: Fair	Stiff clay: Fair	Stiff clay: Fair	Brown lateritic: Very fair	Stiff clay: Poor
Topography	Flat	Fairly hilly	Undulating	Flat	Flat	Undulating	Fairly hilly	Fairly hilly	Very hilly	Undulating	Fairly hilly
History prior to planting	Virgin	Virgin	Cultivated	Virgin	Virgin	Virgin	Virgin	Cultivated	Cultivated	Cultivated	Cultivated
YIELDS: lb. per acre per annum	O M s.e.	O M s.e.	O M s.e.	O M s.e.	O M s.e.	O M s.e.	O M s.e.	O M s.e.	O M s.e.	O M s.e.	O M s.e.
1930	300 321 14	.. .. ..	.. .. ..	.. .. ..	.. .. ..	.. .. ..	.. .. ..	.. .. ..	.. .. ..	.. .. ..	.. .. ..
1931	505 549 11	475 472 8	656 693 27	595 638 21	437 442 12	620 624 ..	370 379 18	386 380 ..	352 379 19	261 340 24	331 372 15
1932	516 520 ..	555 571 ..	.. .. ..	657 676 ..	498 508 ..	597 599 ..	345 400 18	520 514 ..	359 430 40	192 375 64	{387 422 11
1933	494 520 15	500 520 ..	.. .. ..	564 563 ..	539 570 20	522 552 17	432 500 17	517 534 ..	388 460 48	215 382 38	.. .. ..
1934	563 606 ..	290 296 15	578 632 26	422 473 48	487 503 ..	577 578 ..	379 467 23	532 544 26	369 451 ..	253 441 44	201 373 18
1935	591 600 ..	322 349 ..	608 723 32	479 532 34	361 368 ..	548 553 ..	157 217 12	567 568 ..	400 451 ..	283 544 ..	160 322 20
ECONOMIC RESPONSE	Not yet	Not yet	Fifth year	Fifth year	Not yet	Not yet	Second year	Not yet	Second year	First year	At change-over (third year)
GROWTH: Girth-increment in inches per annum											
1931–2	O 2·55	O 0·62	O 0·60	O 0·90	O 0·64	O 1·20	O 0·35	O 0·65	O 0·45	O 0·20	O 0·10
1935–6	O 1·00	O 0·41	O 0·24	O 0·39	O 0·61	O 0·42	O 0·10	O 0·65	O 0·38	O 0·20	O 0·01
	N 1·61	N 0·74	N 0·63	N 0·55	N 1·06	N 0·79	N 0·42	N 1·00	N 0·82	N 0·62	N 0·91
	NK 1·45	NK 0·70	NK 0·72	NK 0·58	NK 1·05	NK 0·78	NK 0·20	NK 0·82	NK 0·93	NK 0·64	NK 0·91
	NPKX 1·55	NPKX 0·73	NPKX 0·61	NPKX 0·61	NPKX 1·91	NPKX 1·25	NPKX 0·41	NPKX 1·15*	NPKX 1·06*	NPKX 0·42*	NPKX 0·56
	NPK 1·56	NPK 0·88	NPK 0·61	NPK 0·61	NPK 1·48	NPK 0·98	NPK 0·43	NPK 0·89	NPK 0·96	NPK 0·65	NPK 0·98

O = Control: N = Sulphate of ammonia only, 5½ lb. per tree: NK = sulphate of ammonia, 5½ lb. per tree, and muriate of potash, 3½ lb. per tree.
NPKX = Complete organic, meat-meal ('Sterameal'—7 per cent. N: 10 per cent. P_2O_5; 5 per cent. K_2O), 11 lb. per tree (* Expts. 8, 9 and 10, 9 lb. per tree).
NPK = Complete inorganic (Nitrophoska = 16½ per cent. N; 16½ per cent. P_2O_5; 21 per cent. K_2O), 6½ lb. per tree. Ratio of amounts of nitrogen (treatment N = 1) NK:NPKX:NPK = 1:0·67:0·92.
M = Average for all manured plots, differences between treatments not being significant. s.e. is the standard error of a difference between M and O.
Sudden drops in yield are due to change-over of cut to a new panel.
Economic return reckoned for rubber at 6*d*. per lb. (with Tamil tappers on daily wages) and for treatment with sulphate of ammonia only.

Experiment No. 10 is the outstandingly successful case, and a graph of the average annual yield is shown in Fig. 2. The period happens to cover the tapping of one complete 42-in. panel. Improvement in yield was immediate, and has been progressive to the present time, the average benefit to all manured plots in the fifth year with the tapping-cut nearing the base of the tree being an increase of 92 per cent. in yield. Both in appearance and performance the manured areas have advanced from poor backward rubber with no future to a very good stand with further

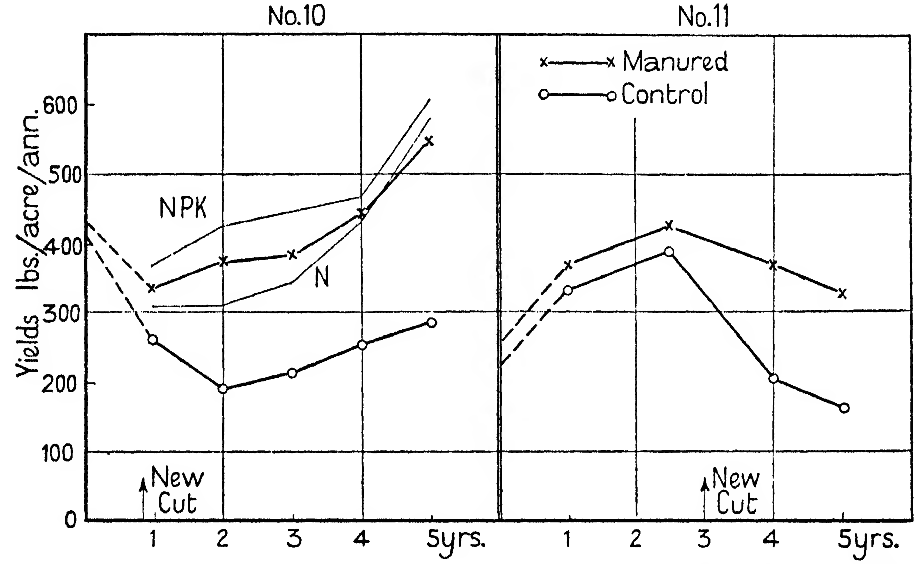

FIG. 2. Two of Dunlop's experiments. Plots manured annually. The yield-value at the beginning is a reliable estimate only. Since the height of cut repeats itself in the fifth year the yield would do so also if conditions remained unchanged. Manuring has therefore definitely advanced the yielding capacity, but the controls have deteriorated.

improvement still in store. A photometer test of ground-shade on the plots towards the end of 1935 showed eight times as much light coming through the foliage of the control trees as through the manured. The special reasons for the outstanding response in yield cannot yet be exactly defined. The land is undulating with a clay soil and laterite gravel. The soil character varies in patches from a light-coloured, stiff phase showing impeded water-circulation to a red, softer phase with much easier drainage. There is marked response on both phases, which suggests that there is a big determining factor in the trees themselves. The point of similarity with the other two cases of quick response, namely the HAPM white-soil experiment (p. 303) and No. 10 I.C.I. series (p. 309), is that the trees were young, though in great need, being in this case in their fourteenth year when manuring began. The land also had been under cultivation before planting, and the stand is of the orchard type. In respect of soil there is little similarity to the responsive white soil of Sumatra.

In order to bring out a special feature in this experiment separate curves are shown for the N and NPK treatments. It will be noticed that the plots receiving nitrogen alone were much behind the completely manured plots for the first two or three years, but that later a rapid overhauling took place. One may suppose that the trees were originally in need of minerals as well as nitrogen, but that there is a cumulative effect of sulphate of ammonia which gradually allows the extra minerals to be found. This may be a reaction in the soil, but is more likely to represent a reaction of the trees which can better exploit the soil when root-expansion and improved transpiration follow the restoration of the leaf-canopy. Thus the mineral-deficiency is not fundamental like that of nitrogen, and although in cases like this additions of minerals at first greatly assist in a quick recovery, there is obviously no need to supply them continuously as a support to nitrogen manuring.

The site of Expt. No. 11, whose results are also shown in Fig. 2, is similar to No. 10 in most obvious respects, but the events took a different course. No benefit was shown at first, but when, after nearly three years' manuring, the tapping-cut was changed over to a new panel, there was a much greater fall in yield on the controls than on the manured plots. During the first two years on the new panel there has been some tendency for the benefit to increase, although the yield itself is falling slightly owing to the peculiar position of the cut. Yield on the manured plots is now double that on the controls. The behaviour of No. 10 seems at first sight to be somewhat incongruous with that of No. 11, for whereas No. 10 gave immediate increases, the response of No. 11 was delayed and seems to show mainly as an arrest of deterioration. But deterioration can only be judged properly by comparison of yields at similar heights on successive tapping-panels, and the data in Fig. 2 are just extensive enough for such a judgement to be attempted. The period of five years just covers the length of time taken for the cut to travel down one tapping-panel, so that, if conditions had been stable, the curves would at the end of the five-year period be back at the values at which they started, i.e. the curves would exactly repeat. This enables one to say, on examining the actual levels which the curves have reached, that in both experiments the divergence between the manured and control curves can be ascribed in about equal proportions to deterioration of the unmanured rubber and to real improvement of the manured. This confirms the conclusion expressed in section 2 above.

No. 7 is a good case of gradual improvement in old and fairly well-grown rubber. Here nitrogen alone proved fully as good as other treatments even from the first, since there had been no mineral deficiency produced by earlier cropping. The benefit reached an economic level after the second year of manuring, and although the yields received a severe check in the last year, as is usual in old rubber when the tapping changes to a new high cut, the percentage benefit took a bound forward from 23 to 38 per cent. at the change-over. No. 9 gave fair response; Nos. 3 and 4 are giving a late response after being doubtful for the first 3 or 4 years.

Combining the yields for all six cases of response and comparing treatments on a percentage basis we have:

TABLE 4. *Yields. Comparison of Treatments, Responsive Cases*

Treatment	*1931*	*1932*	*1933*	*1934*	*1935*
Control	100	100	100	100	100
N only	109	119	118	137	145
NK	111	123	121	139	148
NPKX (organic)	111	117	114	131	139
NPK	116	130	128	143	152

From this table it may safely be deduced that, for the fairly heavy dressings given to all plots, nitrogen by itself produces nearly a full effect, and that the extra cost of the other treatments would be quite unjustified commercially. The organic treatment has received one-third less nitrogen than the others (though at much greater cost), which would account for its being a little behind. We obviously need to know more about the optimum dosage before a closer or final interpretation could be attempted.

The five remaining cases of this group show so far effects in yield which are too small to be of any real value. Effects on appearance are, however, very marked in practically every case—indeed, they are so marked that an uninstructed observer would sometimes hardly credit that plots so different in appearance could produce yields so nearly the same. Future benefits therefore seem certain.

Table 3 indicates that a yield-level of about 425 lb. per acre per annum separates the lower-yielding cases which respond quickly from those higher-yielding ones which are slow. The cases of biennial treatment of Table 2, being all save one in the higher-yielding group, do not therefore compare suitably on the question of dosage with the annually treated experiments of Table 3. It seems safe to say, however, that the annual treatment is necessary where there is much leeway to be made good, but that it is certainly too heavy where the circumstances only require that deterioration be prevented. If manuring is started in time, i.e. as soon as failure in foliage is apparent, applications at long intervals will usually suffice.

5. *Effects on Girth and Bark*

The effects of manures upon girth-increment are more immediate and definite than upon yield, for growth-improvement is established in every case without exception. Since the activity of bark-renewal is in a sense complementary to girth-increment, improvement of the one may be assumed to follow the improvement of the other. Also, since girth-increase comes before yield-increase and is easier to measure accurately, it should be given close attention.

Girth-records have been kept in all the experiments described under section 4 (Dunlop), and appear to form the best means of classifying their behaviour. Growth-rates at the time of the first manuring varied from 2·2 in. per annum, on the youngest experiment just in tapping, to

a negligible figure of say 0·1 in. per annum on the most starved and stunted site (No. 11). All four cases which gave ready yield-response were growing at a rate of less than 0·5 in. per annum when manuring began and all other cases above this rate. Thus the standard of 0·5 in. per annum could have been used at the beginning to give a correct forecast of those cases which would quickly respond in yield. Further, the two experiments which gave delayed response had fallen below the same standard (on the controls) when the economic return began to show. In the three cases where response is most obviously lacking the untreated plots are still growing at a rate of 0·6 in. per annum or over. Again we may note that all manured plots (with one exception and that the oldest rubber) have been raised above the half-inch standard by the treatment. It therefore appears that a standard growth-rate of about ½ in. per annum forms, for this representative set of experiments, a natural limit below which deterioration is so marked that manuring is urgently called for, but above which the bark is still maintained in a fairly satisfactory condition. Such a criterion is easily applied (without the uncertainties or ambiguities which affect measures of yield, bark-thickness, and so on), and appears to have great promise in assisting diagnosis and treatment. With fuller knowledge the standard suggested could be adjusted for age of trees, and perhaps also for different soil or climatic regions. An analysis of the cases given in section 2 afforded full support to this conclusion, that the growth-rate is a good indicator for judging the expectation of response.

The relationships of the girth-increments for the different treatments in the experiments described under section 4 were as follows (average all experiments):

TABLE 5. *Girth-increase*

Control	100
N only	207
NK	199
Organic	233
NPK	227

In most cases the plots settled down quickly to a new growth-rate corresponding to the improved nutrition. Since the organic treatment contained much less nitrogen than the other treatments, and yet heads the list, it would appear to have some special value for growth-stimulation, though nothing exceptional is shown yet for yield-increase. Examination discloses that this special feature is confined to the cases of most rapid general growth.

Bark-renewal is found to follow suit with girth-increments, though here the technique of measurement is subject to a much greater error. The following result (Table 6) is given by combining the bark-measurements of 6 experiments (I.C.I) described under section 3 and receiving biennial treatments. The average period of manuring was 3¼ years and the average period of renewal 2¼ years, i.e. the renewal-period had been in all cases within the period of manuring. Plot-figures were averages of about 100 trees, and 3,400 trees altogether are represented in the

analysis. The significance on Fisher's z test was just over the 1 per cent. point.

TABLE 6

Bark-thickness (in mm.)		*Differences* (due to manure)
O	6·53	..
N	7·68	1·15
NPK	7·72	1·19
Standard error	0·26	0·37

Bark-renewal is improved on the average by over 17 per cent., although in individual cases the figure rose to nearly 40 per cent. Both the above tables strongly confirm the conclusion that nitrogen is the only element of outstanding importance in fully mature rubber.[1]

6. *Cases of Lack of Response*

Although five of the experiments described in the preceding group of cases (4) have not yet given economic response, the improvement in appearance shows that manuring has benefited the trees and gives promise for the future. There are cases, however, where good foliage without manuring suggests a nutritional sufficiency, and the following typical one shows that further addition of nutrients does not in such circumstances force on yields. This experiment, one of the I.C.I. series, was laid out in 1931 on tall well-grown trees, planted in 1910, and situated on a stiff but well-drained coastal clay soil. The lay-out was a 4×4 Latin square of 1½-acre plots (125 trees each) and included the following treatments: O-control, PK-superphosphate plus sulphate of potash, NPK-complete fertilizer (Enpekay No. 1), and NPKX-complete fertilizer together with traces of the minor elements, copper, zinc, and manganese. The fertilizers were applied biennially at rates calculated to supply 0·81 lb. P_2O_5 and 0·98 lb. K_2O per tree to all the manured series, and 0·81 lb. N to the two which received complete fertilizer.

[1] Measurements of bark on the Dunlop 25-plot experiments were not complete at the time of writing. The figures available all show a very high level of significance and give the following percentage comparisons:

Bark-thickness Dunlop 25-plot Experiments (*two to five years' renewal*)

Treatment	A *Control*	B N	C NK	D NPKX	E NPK
Experiment No. 1	8·54 mm. = 100	105	101	102	103
,, No. 2	6·45 mm. = 100	111	110	120	119
,, No. 5	6·42 mm. = 100	110	107	118	117
,, No. 8	6·01 mm. = 100	114	112	119	113
,, No. 9	5·49 mm. = 100	124	120	130	126
,, No. 10	5·55 mm. = 100	118	116	122	119

The organic treatment D has given the thickest bark in most cases, in spite of the smaller amount of nitrogen applied, and the observation is general that the bark is softest on these plots. The main conclusion seems to be that, although the bark-thickness has increased along with the other improvements, this measurement does not afford a specially good index for estimating yield-responses.

When the experiment began the trees were yielding 550–600 lb. of dry rubber per acre, and throughout its course there has been little sign of any decline in yield. In this case the trees appear to have been able to find all the nutrients they required in the soil, so that manuring has produced little or no improvement. These flat, coastal clay soils are known to be comparatively rich, and, where the rubber is unsatisfactory, suffer more from lack of drainage or poor soil-texture than from deficiency in nutrient elements. Normally they grow excellent stands of rubber with heavy dark-green foliage and satisfactory yields, and attempts to improve them by manuring have not been successful. Cases are known where these soils have been replanted after carrying a stand of rubber for upwards of 30–35 years, following the previous cultivation of sugar or other crops, and the young trees have made growth equal to that on newly opened virgin jungle soils without any fertilizers being applied.

7. *Special Cases of Mineral Deficiency*

As already mentioned, the great majority of experiments on mature rubber show that there is generally little need to apply phosphoric acid and potash in addition to nitrogen. Special cases are known, however, where applications of minerals have produced a marked response after nitrogen had apparently failed to do so. Unfortunately, accurate experimental data are not forthcoming, but these cases are of two kinds. The first is recorded from tracts of sandy soil containing much black organic matter and showing a gritty white surface, a good example of which occurs in Central Perak. This soil is particularly deficient in potash, resulting in stunted growth of the trees and in die-back of the branches, associated with a peculiar yellowing or browning of the leaves, which appears to be a form of rim-blight. One of the earliest of the I.C.I. experiments was put down on this type of soil and included a series manured with sulphate of potash, but it was abandoned by the estate concerned during the period of economic depression before any records had been taken. In spite of this, visual effects on the trees were so great that extensive manuring with potash was undertaken later. Although no accurate estimate can be made of the effect on yield, there appears to be no doubt that on neighbouring estates considerable areas have since been resuscitated by rectifying the potash deficiency in this particular type of soil.

The second kind of case is met mainly in the south of the peninsula on certain areas where previous cropping, heavy erosion, and long exposure have so exhausted the soil that rubber is hardly able to grow at all. The trees here are of the small orchard type and remain permanently stunted. On these areas deficiency in phosphate appears to be the main factor limiting growth, and striking results, first in growth and later in yield, have been shown to follow the application of phosphate fertilizers. Until experimental results are available it is not possible to enlarge further on these special cases, but they are worth noting as exceptions to the general rule that applications of minerals are not required on mature rubber.

8. *Other Problems Related to Manuring*

Cultivation with undergrowth.—In order to maintain more natural and sheltered soil conditions on rubber estates, the practice of allowing controlled undergrowth is steadily growing in favour. Natural forms are permitted owing to the difficulties in introducing legumes beneath mature rubber which are as yet not generally surmounted. There are at the present time no experimental results capable of unambiguous interpretation, but this paper would be incomplete without some reference to the bearing of manuring on such practices. The great point to be emphasized is that the two methods are not antagonistic but in many ways complementary.

Competition between cover and trees will always occur, and good management consists in keeping the balance on the side of the trees. Disastrous consequence can follow if undesirable forms of undergrowth get out of hand. Now the one thing required for natural control is overhead shade, and nothing is more certain than the recovery of leaf under manuring: a bag of sulphate of ammonia is the equivalent of new leaves and more shade. In that way the fertilizer will partly pay for itself in saving costs on weed-control. It is found that sulphate of ammonia is taken up much more readily by the more vigorous roots of the trees than by the undergrowth, and it has proved quite possible to make the application without first weeding the ground, though such preparation of patches for application may usually be advisable.

The natural effect of the undergrowth is to improve the nitrogen status (or activity) of the soil, but the process is always slow. This slow effect may be sufficient in good rubber, but will in most cases be quite inadequate to meet the very pressing needs for recovery. Manuring, on the other hand, can raise the nitrogen supplies immediately, and to any desired amount. It is, therefore, a necessary adjunct to rapid improvement, even if the so-called 'forestry' methods should prove adequate by themselves after a new balance at a higher level of soil activity has been attained.

Oidium leaf-disease.—Increasing anxiety in recent years regarding the ill effects of *Oidium* would seem to be very largely due to the increasing weakness of the trees, if the districts chiefly concerned are any criterion. Apart from the question of greater susceptibility due to slower development of new leaves after wintering, the strain of renewal after a second defoliation from disease is a very severe one on trees whose poor reserves are already exhausted. Manuring enables these reserves to be restored and maintained, so that although it cannot strictly be regarded as curative, it strongly counteracts and alleviates the bad effects of *Oidium*, and should be regarded in most cases as a necessary and obvious support to any other measures. Sulphate of ammonia enables the new leaves to be produced easily and their development through the vulnerable stages to be quicker.

Soil acidity.—Rubber soils are naturally acid, having a pH value usually around 4·6 to 4·8, but sometimes going as low as 3·0 or even lower. It is probable that, under the heavy leaching which is normal,

residual effects of the fertilizers used are not important. Grantham's experiment indicates that prolonged manuring with nitrate of soda is not harmful. In one case our results led to the suspicion that prolonged use of calcium cyanamide (which would build up lime in the soil) is not desirable. We are of opinion that any acidity resulting from continued use of sulphate of ammonia will be advantageous rather than detrimental.

V. *Young Rubber and Replanting*

Young rubber offers a much simpler problem than the old, because if growth-response is obtained the economic benefit of early maturity is very great and yields may be left to look after themselves. Here, as in older rubber, manures may be ineffective if conditions are good. This is sufficiently proved by the R.R.I. experiment [12] on a virgin soil, in which manuring had no effects on growth-rate up to maturity on a seedling area which made 4 to 6 in. girth per year without assistance. Later tapping-figures may show more result than girth-increase has done. But if conditions are poor, as in replanted sites, the benefit of manures can be in no doubt. One such experiment was started in 1935 on six-year-old replanted rubber (old rubber cleared 1925 and followed by four years' abandonment, then replanted mixed seedlings and buddings, 1929, without manures) and gave the following result after the first year of manuring:

TABLE 7. *Young Replanted Rubber*

	Girth-increment (in. per annum)	
	Buddings	*Seedlings*
O (Control)	1·56	2·50
N (2 lb. sulphate of ammonia per tree) . .	1·66	4·16
NK (sulphate of ammonia plus sulphate of potash)	2·40	3·80
NPK (3 lb. per tree Enpekay No. 1) . .	2·66	4·52
Standard error	0·15	

Here the chief feature is the small effect of nitrogen on the buddings unless backed by potash, though this does not show with the seedlings.

Another case in which phosphate was the mineral required is given in Table 8. These are the first year's results of an experiment on young

TABLE 8. *Young Rubber, Buddings*

	Girth-increment (in. per annum)	*Differences due to manuring*
O (control)	3·39	..
N (sulphate of ammonia only) . .	3·30	−0·09
NP (Nicifos B)	4·26	+0·87
NPK (Enpekay No. 1)	4·30	+0·91
NPKX ('Sterameal' young-rubber mixture) .	4·18	+0·79
Standard error	0·16	0·23

rubber, planted in 1927–8 on old tapioca land and budded in 1931, but not manured till 1935 (lay-out four randomized blocks). Here the lack of result from nitrogen without phosphate is very striking and gives a good example of the possibility of making mistakes without proper guidance. The effect of phosphate alone is not tested, but a number of other results suggest that it may be by far the most important element in the combinations. The organic treatment had rather less phosphate than the other treatments (though the same amount of nitrogen), which accounts for its slightly lower result.

Young trees seem much more susceptible to mineral deficiencies than older ones, and phosphate or potash may take the place of first importance, although the assistance of nitrogen may be valuable. Many cases are found to require only one mineral element, so that economy can be effected if such knowledge is gained. It is easily obtained by simple experiment during the early rounds of manuring replantings (when complete fertilizer can in general be given, for amounts and costs are small), and then, if need be, the element not required can be stopped.

The following results (Table 9) were obtained in a replanting experiment on budded rubber (Clone BD.5) on a rather open loam soil (first cleared 1905). Manuring started in March 1933 at about 18 months old, and the figures given are the mean increases in girth during the third completed year of manuring. The lay-out is a 4×4 Latin square (O, P, K, PK), with each plot split for added nitrogen. The effect of PK is fully significant and that of K fairly so, but the effects of N and of P are not significant.

TABLE 9. *Annual Girth-increment Young Budded Rubber (BD.5), Inches*

Treatment	*Without N*	*With N*	*Difference due to N*	*Average*	*Difference over control*
O . .	2·70	2·63	−0·07	2·67	. .
P . .	2·71	2·92	+0·21	2·82	0·15
K . .	3·01	2·89	−0·12	2·95	0·28
PK . .	3·35	3·57	+0·22	3·46	0·79
Standard error	0·21	0·21	0·30	0·15	0·21

Fisher's *z* test showed a value just better than the 5 per cent. point for the whole experiment. Beneficial interaction between P and K is indicated with fair significance. As regards less significant suggestions, it may be noticed that nitrogen has no effect when alone or with potash, but that in the presence of phosphate it appears to have some small effect. This interaction has appeared in other cases. Briefly, the experiment shows potash to be the most important element when used singly, but the beneficial interactions between all elements when applied together makes a complete fertilizer the best choice. The NPK treatment has produced 25 per cent. increase in the rate of growth during the whole period. If that benefit were simply maintained (and there are signs that it is accelerating) the PK plots would come to maturity more

than 1 year, and the NPK plots nearly 2 years, before the controls, which would in itself repay the cost of manures. The yearly increment of 3½ in. per annum for the NPK plots, though fairly low, may be reckoned quite good for the Clone BD.5, which branches late and puts on girth only slowly at first. This experiment again demonstrates the importance of minerals for young rubber. The insignificant effect of N may be reckoned rather exceptional, but it usually takes a place of second importance at that stage. In other cases on heavier soils one may expect to find P more prominent in its results, and in some such cases K has been found to be of no importance.

Such results are quite general and will probably be much improved upon when manuring is started at first planting. The only limiting factor to successful replanting (omitting root-disease) is whether the soil fails to afford a sufficiently well-drained and aerated situation for root-growth. Rubber does not do well on very heavy soils in which air- and water-movement are slow, even under proper drainage systems, and it cannot be expected that fertilizers will overcome such limitations. If natural drainage is adequate the early stages of growth can certainly be supported by artificial application of plant-food (as witness the successful growth of plants in water-cultures), the while humus recovery and soil activity are forwarded by means of cultivating covers. Enough has been said to show that replanting without including a manurial scheme would be highly hazardous. It should also be emphasized that manuring in the earliest stages is important, or the plants may take on a set sluggishness from which it is difficult to rouse them.

VI. *Recapitulation*

Taking all the experience covered directly or indirectly in the present paper we seem justified now in attempting to make generalizations to serve as guidance in practice. Cases where yield-levels have been immediately raised are comparatively rare, and seem to be associated with rubber young enough to have retained some vigour, but backward on account of the soil being exhausted by previous cultivation. These 'orchard-type' cases may justify a first dressing of complete fertilizer, but afterwards nitrogen alone should be given. In older rubber, where deterioration has occurred at some time late in the planting history, further deterioration may with certainty be arrested by manuring with sulphate of ammonia, and a degree of restoration will probably follow, particularly where age is not too advanced. The improvements occur in two stages, the first being an increase of the order 10 per cent. during the immediate phase of improving foliage, and the second a much larger increase beginning in the fourth or fifth year, as benefit to the bark becomes effective. Relatively high yield-levels are not generally raised by manuring. The magnitude of the yield-increases therefore depends largely upon the degree of restoration required, and they will usually soon become economic if the yield-level of the stand has fallen below 400 lb. per acre per annum. Frequency of application should be measured in terms of degree of starvation, and if a beginning is made as soon as deterioration shows in foliage, then applications with two-,

three-, or even four-year intervals may suffice to maintain good foliage, from which good bark-renewal and stable yield may be assumed to follow.

If deterioration is fairly advanced the immediate response may be enough to justify economically a yearly application. As a standard for judging this, we arrive tentatively at a growth rate of half-an-inch girth-increment per year. If growth is much better than this, then deterioration of yield is probably not due for some years and a calculable return is not in sight. Manuring would, however, seem justified at suitable intervals so soon as need is shown, as a measure of insurance against loss, which is none the less real for being distant in time. When growth is below the standard named, need is urgent and recovery is likely to be quick enough to justify yearly expenditure and to give a calculable return in increased yields.

The experiments examined prove fully that nitrogen is the fundamental manurial need, and they have not brought to light any advantage as to yield commensurate with extra cost from the addition of minerals to nitrogen on old rubber, nor from the use of organic forms. Any departure, therefore, from the rule of using sulphate of ammonia alone in old rubber would seem to require strong justification as a special case. Such cases are likely to occur on a special type of potash-deficient soil, and sometimes on soils long cleared before planting. In younger areas where growth is of prime importance, whether to hasten maturity or to pull stunted rubber out of premature senility, the addition of minerals to nitrogen is usually required as a first stage, and the possibility that organic fertilizers may sometimes have a special advantage to justify in part their extra cost is not entirely ruled out.

Where replanting is feasible, it is in the long run an alternative to be preferred to rejuvenation of old stands, because of the higher-yielding material available for new stands. Manuring of the young rubber must then be considered quite essential for success. Complete fertilizers are best, for nitrogen without minerals is ineffective in these cases, and simple experiments can be run concurrently with the early stages of planting to decide which element, if any, may be dispensed with. The design of such an experiment should cover interactions as well as direct effects, all combinations being tried, namely N, P, K, NP, NK, PK, and NPK. If there are no outstanding problems concerning drainage, hard-pan, or root-disease, then the success of replanting should be assured by the use of fertilizers and a proper policy of humus-conservation and soil improvement by the cultivation of covers.

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UNMANURED MANURED

TYPICAL EFFECT OF MANURING ON FOLIAGE

This experiment was laid down on poor mature rubber which was carrying very thin foliage (see unmanured plot). Sulphate of ammonia was applied in 1931 and again in 1933, and the photograph (taken in 1935) shows the marked improvement which has taken place in the foliage as a result of manuring

THE ROOT-SYSTEM OF THE SUGAR-CANE

Pt. III. THE EARLY DEVELOPMENT OF THE ROOT-SYSTEM OF SUGAR-CANE IN MAURITIUS

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WITH PLATE 17

Introduction.—In the second paper of this series (this *J.*, 1936, **4**, 208) the mature root-systems of the most important sugar-cane types were described, and the root-systems of several other varieties, important commercially or for breeding, have been described in detail in Bulletin No. 6 of the Sugar-cane Research Station, Mauritius. It is important to know exactly how these mature root-systems are built up, especially those of the commercial varieties, for these varieties are manured and cultivated when the root-system is very immature. Data on the quantitative development of the root-system of virgin, or plant, canes of White Tanna have been presented in Bulletin No. 7 of this Station.

The present paper contains qualitative observations on the distribution and extent of the root-system at various times up to six months from the date of planting, the varieties used being White Tanna, BH. 10 (12), and POJ. 2878. The root-systems were examined, by the 'block' method, when the plants were 2, 3, 5, and 6 months old, and were subsequently reconstructed in specially made frames. Climatic conditions were very favourable during the whole period of growth.

The Root-Systems at Two Months (Plate 17, Figs. 1, 2)

Some of the relevant data on the two-month-old root-systems are summarized in Table 1.

TABLE 1

	White Tanna	*BH. 10 (12)*	*POJ. 2878*
Distribution, length, &c.	Uniform. Sett-roots mainly inactive. Longest roots 33 in. Aver. point of termination 20–25 in. from stool. Max. depth 24 in., mean depth 10–12 in.	Slightly asymmetrical, shallow. A few sett-roots active. Mainly superficial roots; longest 39 in. Aver. pt. of termination 24 in. Max. depth 18 in., mean depth 12 in.	Mostly active sett-roots, longest 30 in. Longest superficial roots 12 in.; mean length 3-4 in. Max. depth of buttress-roots 18 in.
No. of roots:			
Total . .	175	138	. .
Superficial .	155	102	37
Buttress . .	20	34	2
Buttress on primary shoots .	2	2	. .
Buttress on secondary shoots	18	32	. .

Thus there is a marked difference in the rate of development of the root-system in the three varieties, POJ. 2878 being outstandingly slow. A very interesting feature which appears to have been established for all three varieties is that the proportion of buttress-roots to superficial roots on the primary shoots is very much lower than on the secondary shoots. The thicker superficial roots of White Tanna often attained a diameter of 5 mm. and branched only towards their terminations. In BH. 10 (12) the slight asymmetry in distribution of roots was correlated with the position of the shoots, root-formation being more vigorous on the side of the cutting where most buds had developed. The root-system of BH. 10 (12) was more shallow, but had a slightly greater spread than that of White Tanna at 2 months; there were still many active sett-roots, indicating a less advanced state of development, as compared with White Tanna. The root-system of POJ. 2878 at 2 months was more like that of the other two varieties at 1 month; it still consisted, in the main, of sett-roots, and was only in the earliest stages of formation.

The Root-Systems at Three Months (*Plate 17, Figs. 3, 4, 5*)

The data on the 3-month-old root-systems are summarized in Table 2.

TABLE 2

	White Tanna	*BH. 10 (12)*	*POJ. 2878*
Distribution, length, &c.	Increase in number, spread and branching of both types. Superficial system localized in a zone 4–16 in. deep; max. length 42 in. Buttress-system, lateral spread 24 in., max. depth 34 in., mean depth 20–24 in.	Increase over 2-month system less marked than in White Tanna. Distribution more uniform. Number of superficial roots less than in White Tanna; max. length 50 in. Buttress-system, lateral spread 24 in., max. depth 30 in., mean depth 24 in.	Marked development between 2 and 3 months. Sett-roots mostly inactive. Superficial roots, max. length 34 in., mean spread 24 in., depth 14 in. Buttress-roots well developed but pass downwards almost vertically; max. depth 27 in., mean depth 14 in.
No. of roots:			
Superficial .	275	202	216
Buttress . .	26	41	34
Buttress on primary shoots .	. .	. .	11
Buttress on secondary shoots	. .	. .	23
Sett-roots .	very few	few	. .

The progress of root-growth between the second and third month was quite marked in the three varieties, but more in White Tanna and POJ. 2878 than in BH. 10 (12). In all three varieties there were very few roots in the first 3 in. of soil. The mean spread of the superficial system is such that most of the interline is fairly intimately explored by the roots at 3 months. The development of buttress-roots is more marked in BH. 10 (12) than in the other varieties. The root-system

as a whole, however, is best developed in White Tanna at this stage. There was very active root-growth in POJ. 2878 between the second and third months; the system at three months showed much more change from that at two months than in the other two varieties.

The Root-Systems at Five Months

Table 3 summarizes the main features of the 5-month-old root-systems.

TABLE 3

	White Tanna	*BH. 10 (12)*	*POJ. 2878*
Distribution, length, &c.	Marked development between 3 and 5 months. Longest superficial roots 60 in., mean length 36–42 in.; number much increased. Development of buttress-system less marked; max. depth 36 in., mean depth 30 in.	Spread not increased between 3 and 5 months. Few superficial roots 42-48 in.; mean length 24–30 in.; mostly thinner than in White Tanna, but buttress-system more extensive; depth 54 in., mean depth 30–36 in.	Marked increase in length between 3 and 5 months. Superficial roots only in first 12 in.; max. length 30 in. Buttress-system increased, but lateral spread still about 12 in.; longest roots 48 in., mean depth 24–30 in.

Appreciable root-growth, more particularly in length, occurred between the third and fifth months, also increased branching of roots already present, as well as an increase in the number of roots.

Development in White Tanna had occurred mainly in the superficial system, whereas in BH. 10 (12) and POJ. 2878 buttress-root development had been active, tending towards a deeper-seated system.

The Root-Systems at Six Months

Data on the six-month-old systems are given in Table 4.

TABLE 4

White Tanna	*BH. 10 (12)*	*POJ. 2878*
Marked increase in no. of roots; spread also greater. Superficial roots: max. length 72 in., mean length 48–54 in.; abundant down to 18 in.; increased proportion of thick roots.	Superficial roots, considerable increase in no.; max. length 54 in., mean length 36 in. Many penetrated slightly obliquely.	Many new roots, but no increased spread. Superficial roots, mean length 36 in.; penetrated to 18 in.
Buttress-system increased; max. depth 48 in., mean depth 36 in., lateral spread 48 in. No deep roots other than buttress.	Buttress-roots, no increase. A few roots of the wiry-rope type present, forming a poorly developed rope penetrating to 60 in.	Buttress-system more vigorous; max. depth 48 in., mean depth 36–42 in.; lateral spread increased to 24 in. A few deep roots of black, wiry type; one 'embryonic' rope-system penetrating to 60 in.

Development between the fifth and the sixth months was marked, and consisted mainly in the protrusion of a considerable number of new roots, and to a smaller extent in increased growth and branching of roots previously present.

Small rope-systems were observed for the first time at 6 months of age, though the number and degree of organization of these rope-systems were considerably lower than are found in mature root-systems.

Summary of Root-Development in White Tanna, BH. 10 (12) and POJ. 2878

Certain features in the early development of the root-system are common to all three varieties. Thus, root-growth is initiated by the cutting or sett giving rise to the temporary sett-roots, root-functions being afterwards taken over by the shoot-roots, which form the permanent root-system of sugar-cane. Up to 6 months the shoot-roots consist almost exclusively of the two classes of roots which have been described as superficial roots and buttress-roots. The primary shoots (those formed directly from the sett) bear superficial roots almost exclusively. When they bear buttress-roots also, these originate at a later date than the superficial roots. On the other hand, the secondary shoots (i.e. those originating from the primary shoots), and shoots of a higher order, bear a large number of buttress-roots, and these almost always protrude before the superficial roots, which may also be borne on these shoots.

An appreciable time may elapse before the primary shoots form roots, but roots occur on secondary shoots and on those of a higher order at a relatively early age. It is quite common to see young secondary shoots, still below ground-level, and less than 3 in. long, with no unfolded leaves, bearing several buttress-roots, often up to 18 in. in length. The buttress-roots are thus generally the first to protrude on the secondary shoots and those of a higher order, superficial roots being formed later. Primary shoots never have many buttress-roots, and it seems that the greater vigour of growth of secondary and other shoots of higher order, as compared with the primary shoots, may be due to the former being equipped with an adequate buttress-system in addition to superficial roots. The buttress-roots have been shown to be of great importance in the water-economy of the sugar-cane (Bull. No. 5, Sugar-cane Res. Stat., Mauritius).

There are, however, marked differences in the rate of growth of the root-system in the three varieties, the order of merit being White Tanna, BH. 10 (12), POJ. 2878. Under the favourable conditions occurring during the whole of the growing-period, White Tanna had an almost fully developed root-system at 6 months of age, those of the other two varieties at the same age being still immature.

The mature root-system of B.H. 10 (12) had a much greater depth than the 6-month-old system, but that of POJ. 2878 was altogether more extensive as regards spread, number of roots, and depth to which the roots penetrated than the 6-month-old system. There is therefore a

marked difference in the rate of development of the root-system in the three varieties, POJ. 2878 being outstandingly slow; this is in accordance with the behaviour of the three varieties in the field.

The Effect of Subsoiling on Root-Development

Planters have recently taken much interest in subsoiling, which is carried out with an implement capable of breaking up the subsoil *in situ*. It is not yet known whether such treatment causes an increase in yield under normal conditions, but there is evidence that it may be beneficial in the control of *Phytalus Smithi*, as the operation results in the death of some larvae. Preliminary experiments have suggested that the depth of root-growth might be favourably affected by subsoiling, and the work herein described was designed to investigate this problem. Two varieties were used, BH. 10 (12) and White Tanna, and the root-systems were examined in detail by the 'block' method at 3 months of age. Subsoiling was done by carefully removing the top-soil and then breaking up the subsoil to a depth of about 3 ft., the top-soil being then replaced in its original position. Controls were examined at the same time.

White Tanna.—At 3 months of age there was no apparent difference in the aerial portion of the stools; there was, however, a remarkable difference in the root-systems, the most striking being in the depth and density of the roots. Even in the surface-soil, root-development was more vigorous in the treated plots. Superficial roots were longer, more numerous and more branched; this was probably due to the loosening of the surface-soil as a result of its removal and subsequent replacement, which suggests that even a cultivation of the top-soil has a very beneficial effect on root-growth in this region, the absorbing surface being considerably increased. The distinction between thick and thin superficial roots observed in the control stools was not so marked in the treated stools. The mean spread of the superficial roots in the control stools was 4½ to 5 ft., whereas in the treated stools it was 6 ft.

As would be expected, subsoiling had most effect on the buttress-system. The remarkable fact emerged that the nature of the buttress-roots was fundamentally affected by the treatment; they were so modified as to appear almost identical with superficial roots, except that they were lighter in colour. They did not show any of the distortions that are usually typical of these roots; they were cylindrical and ribbed to a slight extent; they branched profusely, giving rise not to the thick, flattened secondaries which they usually bear, but to thin secondaries bearing profuse fibrous rootlets along their entire length. Buttress-roots were more numerous in the treated stools, and their lateral spread extended to 4 ft., with no sharp delimitation. Some buttress-roots had penetrated to 3½ ft., and most of them terminated at a depth of about 3 ft. There were, therefore, at this stage of development only a few roots that penetrated beyond the subsoiled region. In those few which had done so, that portion which had penetrated the undisturbed subsoil showed the normal features of buttress-roots. It appears, therefore,

that the typical morphological characteristics of buttress-roots are not inherent in these roots, but are caused by the nature of the subsoil in which they are located.

BH. 10 (12).—The root-system of BH. 10 (12) was also markedly affected by subsoiling, the depth and number of roots increasing considerably. Branching was also more prolific than in the untreated stools, though not nearly so profuse as in White Tanna. As shown above, branch roots are normally more sparse in BH. 10 (12) than in White Tanna.

Buttress-roots also assumed the features of superficial roots in the treated plot of BH. 10 (12); and there was an even greater difference in the distribution of roots between the treated and untreated stools of BH. 10 (12) than was found in White Tanna. The root-system of the treated stools had a mean spread of 5½ ft., with some superficial roots 4½ ft. long, and a mean depth of 3½ ft., a few penetrating to 4 ft. Plate 17 (Figs. 6 and 7) shows the root-systems of White Tanna and BH. 10 (12), respectively, under subsoiled conditions; they should be compared with Figs. 3 and 4.

To summarize: subsoiling had a very marked effect on the root-system of the two varieties investigated: the treated stools had a greater spread and depth, and the roots were more numerous and more profusely branched. The main differences between buttress-roots and superficial roots disappeared as a result of the treatment, the former assuming the features of the latter.

Discussion

Quantitative and qualitative studies on the development of the young sugar-cane root-system are very important for elucidating problems connected with the cultivation of this crop, and for determining the most efficient cultural methods. They also shed light on the most likely behaviour of the young plants under conditions of drought or attack by *Phytalus*. The spread of the root-system, even in very young canes, shows that when the canes are planted in the ordinary way with 4½–5 ft. between the rows and 2½ ft. between the stools in the row, the interline is fairly intimately explored by the roots, though there are comparatively few roots in the first 3-in.-layer of soil.

It would appear, therefore, that the application of fertilizer in rather concentrated masses in the middle of the clump is not in accordance with the distribution of the absorbing roots, but rather that the fertilizer should be distributed as uniformly as possible over the field, and turned in to a depth of between 3 and 6 in.; it would then stand a good chance of being absorbed. After a time the region of the root nearest the stool becomes conducting only; it is not actively engaged in absorption, though it may still bear some root-hairs, and fertilizer applied in this region is available only to young unbranched roots passing through it. Only in well-advanced canes, whose leaves have effectively closed over the interline, are roots to be found in the very superficial soil layer (down to 2–3 in.), and the broadcasting of fertilizer all over the interline

FIG. 1. White Tanna, 2 mths. old

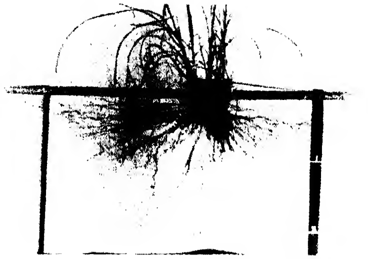

FIG. 2. B.H. 10(12), 2 mths. old

FIG. 3. White Tanna, 3 mths. old

FIG. 4. B.H. 10(12), 3 mths. old

FIG. 5. POJ. 2878, 3 mths old

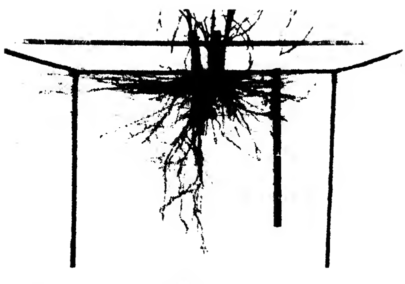

FIG. 6. White Tanna, 3 mths. old (subsoiled)

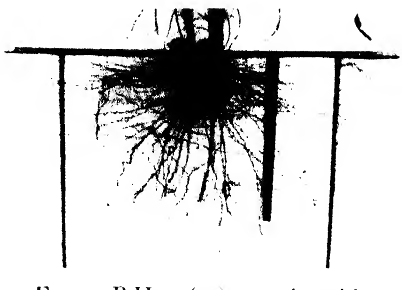

FIG. 7. B.H. 10(12), 3 mths. old (subsoiled)

A SELECTION FROM THE ROOT-SYSTEMS EXAMINED

(Scale in feet)

will therefore not be fully effective unless it is at the same time turned in to the requisite depth.

There is little doubt that application of fertilizer should be made for the benefit of the buttress-roots also, since these form an increasingly important part of the root-system. It is obviously more difficult to apply fertilizer to this class of roots. The operation could only be undertaken profitably before planting the virgin, or plant, crop, by working the fertilizer into the soil at the bottom of the hole. Field experiments to test the efficiency of the new methods of fertilizer applications suggested as a result of root-studies are now in progress, preliminary tests having indicated a superiority of the modified methods over the method hitherto in vogue.

The distribution of roots under subsoiled conditions, and the improvement even of the superficial system in cultivated top-soil, point to the desirability of such intensive cultivation. Even if it so happens that under good growing-conditions no marked increase in yield results (a question still to be solved), it is difficult to imagine that no beneficial effects would occur under abnormal conditions. The root-system produced as a result of subsoiling, being superior in depth, spread, and number of roots, to that of the untreated plants, must result in considerable benefit to the plant under conditions of drought, or high winds accompanying cyclones, or heavy *Phytalus* infestation. The buttress-roots have already been shown to play an important part in the water-relations of sugar-cane, and a buttress-system superior in depth, branching, and number of roots must be of considerable benefit under the dry conditions that are so common in Mauritius. Again, *Phytalus* larvae have been shown to occur mainly in the first foot or so of soil, and an adequate system below this depth should contribute greatly towards increased resistance to the larvae. This, of course, is in addition to the direct killing of larvae caused by the subsoiling operation.

The observations tend to point out that cultivation and 'devidage' (the cutting of trenches near the stools, which are afterwards filled with farmyard manure and covered up, a practice common in Mauritius) should be carried out as early as possible. If the operation is delayed until the plants are 3 to 4 months old, considerable damage to the root-system must result, which, if followed by a drought, might occasion a serious set-back in growth.

Determinations of the total absorbing-surface of the root-system of the three varieties described in this paper have also been completed; they will be discussed in a later publication.

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PAMPAS GRASS (*Cortaderia Selloana* (Schult) Aschers and Graben): A NEW SUPPLEMENTARY FODDER FOR RUMINANTS IN NEW ZEALAND

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WITH PLATES 18, 19

Introduction.—Although the South American pampas grass has become established in many parts of the world as an ornamental plant, the possibility that this quick-growing giant tussock may provide valuable fodder does not seem to have been considered until quite recently, when a New Zealand farmer[1] observed that dairy cattle thrive if allowed to graze this coarse fodder as a winter supplement. The Hauraki Plains district, where the experiments were initiated, comprises the reclaimed estuarial land of the flood plains of the Piako and Waihou rivers, Hauraki Gulf, Auckland. Here the use of pampas grass as a mid-winter and mid-summer supplement has become firmly established with the result that the possible utility of this new fodder is being investigated in other parts of the North Island of New Zealand.

In the Hauraki Plains pampas grass does not naturally regenerate from seed, probably because both sexes are not represented, all stocks being asexually derived from the handsomer female plants. The extensive reclamation of estuarial lands in the Whangarei Harbour, North Auckland, has, however, become in places a nursery of wild pampas seedlings capable of supplying millions of young plants and seeds at a very low cost to farmers.

Pampas grass (*Cortaderia Selloana*[2]) is the well-known South American plume grass, which, according to Lindley and Moore [1], was introduced into Europe in 1843 through seeds from Buenos Aires sent to the Glasnevin Botanical Gardens, Ireland. It is now thoroughly domiciled in Europe and found in almost every large garden in Britain. Hitherto, in Europe and Australia, it has been cultivated entirely for the ornamental effect of the tall, dense, silvery plumes of the female plants; the male plants bear plumes significantly less ornamental, as shown by the two groups of wild plants in the illustration (Plate 18, Fig. 1).

Palatability of Pampas to Cattle and Sheep

It is stated on good authority that pampas grass in South America is regarded as a pest, and is rooted out and burnt wherever it is desired to utilize land for stock-farming; and that it is never eaten by stock in Argentina. Because a plant is little valued in its original habitat is no proof that it will not have a use in another climate and soil, for instance,

[1] Mr. McClean obtained with what is described by breeders as 'a very ordinary herd', a premium of ½d. per lb. for his produce, which was graded 'First Finest Quality' and in yield per acre exceeded that of his neighbours.

[2] The authors are indebted to the Director of Kew Gardens, Sir Arthur Hill, for the correct botanical name of this species.

Pinus radiata (*insignis*) (Monterey pine) and *Cupressus macrocarpa* (Monterey cypress) were not regarded as of much economic use in California, yet when grown in South Africa, Australia, and New Zealand these species provide quick-growing timber and are valued shelter-belts and fences.

Von Mueller [2], an eminent Australian botanist, refers to the pampas grass of Uruguay, Paraguay, and La Plata as an industrial plant because, as was shown by him, paper can be made from its leaves. The Australian soil and climate, like that of South America, may be generally too dry for the completely successful use of pampas grass as a fodder, but W. L. Mardon of Sylvania, Sydney, N.S.W., a farmer of beef cattle, writes that he has always noticed that stock were fond of pampas grass at certain periods. He finds that on fair-quality drained swamp, on fair-quality black, red, or grey soils (on sandstone strata) pampas flourishes like a weed. He states that the sustaining powers of pampas grass are equal, if not superior, to those of most other herbage, and it is beyond dispute that stock relish it and graze it greedily, maintaining virile health.

Over sixty years ago experiments made with pampas grass in the moist North Island of New Zealand by Sir George Grey at Kawau Island, and by Dr. S. M. Curl [3] in the Manawatu district, suggested to them that this coarse grass had been neglected as a fodder plant. Dr. Curl, as early as 1876, recorded that pampas grows to a height of 10 ft., but if within the reach of stock it is kept low, for cattle are particularly fond of its rather coarse leaves, which contain a large amount of nutriment, and grow through both winter and summer, cold having little effect. As young leaves appear, all cattle and sheep will greedily eat them, leaving more delicate herbage.

In New Zealand pampas grass has been long regarded as a suitable shelter-belt plant, particularly in Taranaki, where some form of protection from the ocean winds blowing into the Taranaki Bight is essential in order to obtain the best results from farm stock, especially pigs.

As an ornamental garden plant, pampas was evidently introduced very early into New Zealand, presumably as seed, because in the days of sailing ships plants did not travel well, and both sexes are now widely distributed. In some localities these occur together, and the seedlings spread in waste spaces. There is no record of pampas spreading into well-grazed pasture, since stock will eat out and kill any stray plants. The seed is very small: some gathered from Whangarei averaging 1,800,000 seeds to the pound. It is firmly enclosed by the glumes, so that severe treatment is required to set it free. Commercial 'seed' is therefore bulky and 'fluffy'.[1]

Pampas is to be seen growing as an ornamental plant or as a shelter-hedge in gardens and along the fences of paddocks in practically every part of New Zealand. Nearly everywhere the plants are all female, having been derived from the subdivision of a single plant, the female plant being preferred on account of its larger and more handsome

[1] It is possible to clean seed by vigorous centrifuging, so detaching the seed from the surrounding chaffy scales (the glume and palea), but there is evidence that the viability of such cleaned seed decreases rapidly.

plumes. In some localities (e.g. in parts of Otago and Southland), however, the male plants only are to be seen.

On the stop-banks of the harbour-reclamation works at Whangarei, where stock are practically excluded, thousands of seedling pampas in all stages of growth are to be found. Several counts of areas of flowering seedlings chosen at random in this locality showed an approximately equal number of male and female plants. Some variation occurs, notably in the colour of the panicles, which in some plants is red and in others yellow. By selection from these seedlings different varieties could doubtless be produced, but such variation cannot be expected among plants asexually propagated, as by means of root-cuttings.

Farmers have observed from time to time that cattle grazed with avidity these pampas windbreaks in various North Island stations, but this observation was not followed up and merely resulted in the strengthening of the fences guarding the pampas plantations. Where the pampas can attain sufficient size before being grazed by cattle, there is evidence that fencing is unnecessary, the canes being so thickly disposed and the plants so high (up to 12 ft.) that cattle merely eat the external leaves [4] (Plate 18, Fig. 2).

Despite these numerous observations of cattle grazing pampas grass, the first recorded instance of systematic utilization of this new forage, so far as the authors are aware, is due to Mr. Alec McLean, a farmer who had recently settled on reclaimed salt-marsh land at Waitakaruru, Hauraki Plains, Auckland. This pioneer, noting that comparative analytical data for New Zealand plume grass or toe toe (*Arundo conspicua*) and pampas grass had been published [5] reported to one of us (B. C. A.) in July 1932 that for several years he had been using young pampas grass successfully as a winter fodder for cattle. He had gradually increased his plantations of pampas by subdividing the clumps and planting 6 ft. apart, i.e. approximately a thousand plants to the acre. At the time of writing he had 9 acres under pampas for grazing, and was wintering his herd for the second year on pampas grass as a supplementary fodder. No other supplementary fodder was used, but the stock had a run-off of 48 acres on good cattle pasture. McClean claimed that with the aid of pampas grass he could carry on his farm of 200 acres (including 30–40 acres in the rough state) 200 head of cattle the whole year round. The practice in the district is to use hay as a winter supplement, but McClean found that his stock refused to eat hay when they could get pampas, therefore he abandoned haymaking and now relies wholly on pampas as a supplement. With this mild climate (mean temperature 57°, Lat. 37.25 S., rainfall 45 in., well distributed) and rich soil[1] derived from organic matter and sea-mud, the growth of pasture is practically continuous throughout the year. The illustration (Plate 18, Fig. 3) shows that the water-table is remarkably near the surface. The result of feeding the cattle on pampas was to improve their condition, and to make the health of the whole herd remarkably good. McClean assured inquirers that the yield of butterfat was increased as soon as the herd was put on to pampas, and at once

[1] See analyses of soil at end.

diminished if taken off that supplement. This experience was repeated in other years. His method of feeding is to allow the cattle to graze the pampas in breaks, in winter, with the aid of a movable fence, a method the cattle themselves prefer to having it cut and carted to them. Mr. McClean has modified the original method and now feeds the pampas grass to his herd twice a year instead of once, namely at the two low grass-production periods, midwinter and midsummer, so that pampas grass may become a supplementary fodder available at any time of year. This is a particularly valuable quality for a forage plant in this country of variable seasons. Experiments, including weighing the crop, suggest that if two cuts are made a year as much as 50 tons per acre of green matter may be grown at Hauraki Plains.

The publication in October 1932 of an account of McClean's experiments [4] aroused great interest in the Waikato and adjacent districts, and the discoverer was asked both for information and plants for experimental plantations. These plants were supplied at 30*s*. per 100 subdivisions of the clump, a subdivision consisting of a portion of the stem (preferably one that has not borne flowers) and root. Thus an acre requiring 1,000 plants would cost £15 for plants alone. The senior author (B. C. A.) remembering that he had seen pampas growing wild and regenerating well in the Whangarei estuary (Plate 19, Fig. 7), arranged with the Secretary and Engineer of the Harbour Board, Mr. W. M. Fraser, to utilize unemployed labour to collect seedling pampas plants for sale to farmers. This work, supervised by a skilled nurseryman, has proved very successful in establishing pampas plantations, which by this method are of better quality and much cheaper and easier to establish than by root-subdivision from other clumps, and the mortality of the seedlings is lower than that of root-subdivisions, which suffer great losses in droughts to which seedlings of the right size are highly resistant. The seedlings are baled and carefully packed for transport by railway or boat at 30*s*. per 1,000, and already about 100,000 plants have been distributed by this method.

Although pampas was an admitted success at Hauraki Plains, where both soil conditions and climate are excellent for crop production, it does not follow that the same success will occur in other places where conditions are less favourable. The present year's work suggests that every pampas plant is palatable to cattle if the leaf is not too old; that the plant grows readily on all soils, if sufficiently deep and moist for the roots to obtain the large amount of water required for such a quick-growing, tall graminaceous plant. It apparently flourishes in all climates throughout the Dominion, and has even been reported growing well in the arid district of inland Otago (Kurow) with a rainfall of 20 in. and a severely cold winter with much frost.

Other Farmers' Experiments and Experience

The grazing experiments made in 1935 prove that pampas grass will grow successfully from subdivisions on a poor pumice soil with a deep pumice subsoil (in the Rotorua district), and that under these conditions it is attractive to well-fed calves. It has also proved attractive to stock

on a poor, drained bog-land containing many stumps (Ruakuhia Swamp, near Hamilton), where no other supplementary fodder-plant could be grown.

Mr. George Short, of Dargaville, although he has never grown pampas grass for fodder alone, has used it as a dual-purpose plant—shelter and winter stock-feed—for the past 22 years in various Auckland stations, first at Aka Aka, Waiuku, and latterly in North Wairoa district. All stock are fond of it and will break down good fences to obtain it. He has grown it on drain-banks, in paddocks, and on 'poor gum-land hills', where it thrives. It would be a great asset on exposed farms near the coast, where other shelter does not thrive. Mr. Short's photos of pampas-grass hedges five years old show how it is possible to utilize these hedges without fencing for both shelter and stock-food, if the pampas grass is allowed to grow for a few years until too dense to be eaten out entirely (Plate 18, Fig. 2).

Mr. R. G. Cranwell, of Tuikaramea Road, Frankton Junction, planted ¾ acre with pampas cuttings in the Ruakuhia Swamp, in which no other supplementary fodder could be grown, owing to the submerged stumps and other subsoil conditions. These were grazed off in the winter of 1935. The cattle ate the pampas greedily, and afterwards, when excluded from the plantation, endeavoured to get in again.

Mr. F. R. Seddon, Puketaha, seven miles from Hamilton, on the deep part of the Eureka Swamp, had planted four acres fenced into three strips. Two of these were grazed down last winter (1935), the middle strip being left. The results were satisfactory and are interesting as showing that, when grazed in winter, plants grow again so quickly that by the following autumn their leaf-growth nearly catches up that of young established ungrazed plants which were planted at the same time; the ungrazed plants developing flower-heads which reduces the development of leaf (Plate 18, Fig. 4).

The Ruakura Farm of Instruction, Hamilton, established several plots of pampas plants, derived from different sources. The plot from root-cuttings showed a high mortality, but the plants grown from Whangarei seedlings had practically all 'taken' and showed quite as much leaf-growth as the surviving plants from the cuttings, and, in addition, a far greater amount of stooling throughout the seedling plot. Mr. Rodda, the Manager, was quite convinced that the seedling method was the better way of establishing a plantation.

Mr. Grahame J. W. Harvey, Taupiri, has planted three acres from root-cuttings which will be fed off this winter (1936). This dairy farmer is a skilled plant-propagator, and as he is experimenting with Hauraki cuttings, Whangarei seedlings, and seedlings derived from English purchased seed, valuable results can be expected from his farm (Plate 19, Fig. 5).

Mr. Joe B. Simpson, from long farming experience in Taranaki, states that pampas grass (1) gives good shelter for young tethered calves, (2) provides ideal thatch, (3) is a good rough winter-food, (4) is easy to grow and provides an enormous amount of food, and (5) will improve rough parts of the farm and check growth of noxious weeds.

Major R. A. Wilson informs the authors that on his Himatangi (Foxton) sand-dune property wild pampas grass is eaten down every winter by cattle. The use of pampas grass as a new plant-staple for fixed dunes opens up fresh possibilities for farmers on the dunes. Himatangi appears to be the most southern locality where pampas grass is regenerating naturally.

Four or five of the leading types of soil in the Auckland province have, therefore, been proved to be successful sites for pampas plantations; one of them extremely rich in plant-food, the others extremely poor; the climates being fairly uniform but the soils differing in texture and composition, only one feature being common to all, viz. the good water-supply in the soil available for deep-rooted plants.

Estuarial reclamations would seem to be particularly suitable for pampas plantations, but these differ in mineral plant-food content; Whangarei drained salt marsh being extremely poor and Hauraki estuaries very rich, yet pampas grass flourishes equally in both and is palatable to stock in both; indeed, in some areas at Whangarei the pampas subjected to uncontrolled continuous grazing by cattle has been eaten out and destroyed.

There seems, therefore, to be every prospect of this new fodder-plant becoming a permanent feature of North Island dairy farms, where the soil and subsoil, being fairly deep, allow free descent of pampas roots to the moister subsoil. In the Hauraki Plains the roots have been traced to a depth of 8 ft. The Auckland province is well supplied with water, the annual rainfall on the low levels being generally from 50 to 60 in., falling on 150 to 175 days, whereas in the Hawkes Bay province, the driest area in the North Island, the rainfall is only 35 to 45 in., falling on 125 to 155 days. This area suffers from occasional droughts. It will be interesting to compare the growth of pampas in Hawkes Bay with that on the moister soil of the Auckland provincial district. A number of Hawkes Bay farmers obtained pampas plants from the Hauraki Plains district by subdivision of clumps. Unfortunately, these were planted just before the droughty summer of 1934–5, with the result that almost all of them failed. A similar result attended the trials of an experienced farmer in the Manawatu district under droughty conditions. It is probable that, had seedlings been used instead of subdivisions, the experience would have been much more favourable, as seedling-plants in the Wellington City district, which suffered from the same drought, experienced no mortality.

Although young pampas plants or cuttings are peculiarly susceptible to drought, when once established this new fodder-plant is drought-resistant—another valuable character. In the very dry summer of 1934–5 production of butter-fat in the Hauraki Plains received a severe check; many farm herds yielded only half the usual quantity, and farmers were hard pressed to provide sufficient feed for the cows. Ensilage, saved for the winter, and turnip crops, although only half-grown, were fed on most farms. In spite of the shortage of pasture Mr. McClean enjoyed almost a record season, and the butter-fat production dropped only a few points below his normal average for

January. This happy position he attributed solely to the pampas grass, which he fed regularly, and of which he had sufficient reserve for winter food. The pampas did not appear to suffer in growth or succulence from the drought.

P. W. Smallfield, Fields Superintendent, Department of Agriculture, Auckland, writes recently: 'I visited Mr. A. McClean's farm at Waitakaruru, and watched the dairy herd grazing off a break of pampas grass. Mr. McClean has for a number of years been experimenting with pampas grass as a supplementary stock-food, and recently the usefulness of this plant for general feeding has received wide attention. Some quite useful plantations have already been established on some of the poor peat areas of the Waikato, and there is no doubt that the plant has possibilities. No one could watch the cows on Mr. McClean's farm quietly grazing the pampas plants without being impressed with their potentialities—an actual living fodder for winter feeding.'

That pampas will flourish in the driest Hawkes Bay district, if the requisite cultural conditions and proper method of obtaining the plants are used, is proved by the experience of a farmer at Waipawa, Mr. J. J. Carter, who had exceptionally good results in establishing a batch of seedlings, which, unfortunately, arrived in a very dry state from Whangarei in October. He had, however, the good fortune to plant them in a year which was exceptionally wet, and on well-tilled land between rows of Chou moulier crop. Seen in December 1935 (midsummer in New Zealand) by the junior author (R. E. R. G.) the majority of the plants showed signs of growth, mostly confined to a single leaf appearing from one shoot. Seen again in mid-April 1936 the pampas had made splendid progress, individual plants being 4–6 ft. high and each having more than a dozen shoots. The growth made here was better than any observed in the milder Waikato district, except possibly in one instance. Some seedlings which were apparently quite dead when received, but had been given special treatment in a garden, responded to the better soil conditions of the garden and much surpassed those grown in the field, showing in April growth over 6 ft. long, some having stooled to about 12 in. across, and having a score or more shoots.

This farmer is convinced that, provided seedlings are planted out when received in the place that they are to occupy permanently, which should be well prepared beforehand, seedling pampas responds exceptionally well to good tillage, water-supply, and weeding. He also considers that the plants must be well fenced from stock, as when some sheep were put into the Chou moulier, a splendid crop, they broke into the pampas and ate some plants, neglecting the associated growth of clover, grass, and weeds.

This farmer's experience of the phenomenal growth of seedling pampas has been borne out by the senior author in his garden in Karori, Wellington, 200 miles south of Hawkes Bay and 600 ft. above sea-level, on a windy hill-side, but the ground had been well trenched. Twenty seedlings from Whangarei were planted closely in a line, and when a year old the first cut had to be made because the plants were shading other vegetable crops adjacent. The first cut was made on December 24,

1935, the weight being 25 lb., and the second cut was made on March 11, 1936, the weight being 23 lb.—a total of 48 lb., green weight, for the 20 seedlings. By April 12, 1936, the plants had grown another 15 in. high. Pampas evidently benefits greatly by planting in deeply tilled soil even though air and soil temperatures are low.

Chemical Investigation

In this investigation an attempt has been made to compare the composition of the pampas grass with that of certain well-known forage grasses, and to correlate, if possible, the feeding-value of this grass with the analytical data given below [7, 8]. The analyses of the pampas grass were made on samples taken from the Hauraki Plains. Sample No. 1 was representative of plants that had been fired six to seven months before cutting; sample No. 2 comprised the growth from two plants (110 lb.) during a period of about one year. A detailed account of the chemistry of the carbohydrates of these grasses is not of immediate interest and will be published elsewhere.

Although much information on the mineral-content and composition of the fats and proteins in the various forage grasses is available, the systematic treatment of cell-wall constituents, or structural carbohydrates, and the sugars has been practically neglected.

In Table 1 the chemical composition of pampas grass is compared with that of well-known forage grasses. Special attention has been given to the structural carbohydrates which, besides constituting the bulk of the dry matter in a grass, serve to discriminate between the various species.

It has been customary to group the cell-wall constituents under the term 'crude fibre' and to attribute to this fraction an energy value in the nutrition of ruminants equivalent to that of an equal weight of starch, on the ground that it is broken down in the rumen by bacteria into readily assimilable glucose. Such empirical treatment of the food-value of crude fibre, consisting as it does of a heterogeneous mixture of cellulose, hemicellulose (pentosans, hexosans), and encrusting materials, such as lignin, has not met with complete approval. It is likely, for instance, that the constituents of the crude fibre vary individually in their availability to the animal. The experiments of Furth and Engel (1931), and of Stone and Jones (1892), quoted by Mangold [11], show that the hemicelluloses, like the cellulose, are readily digested by ruminants. In contrast with starch, however, these two constituents are both made available, not by enzymic action, but by bacteria in the rumen ([12] and Schieblich, 1932, quoted in [11]). It is generally accepted that lignin is either not readily available or completely indigestible [11], but according to Woodman and Stewart [13] the digestibility of cellulose is not entirely dependent on the degree of lignification or the lignin-content of the crude fibre, since, for instance, in grass the decrease in digestibility with age is associated with a relatively small increase in lignin-content. The crude fibre constitutes the essential material of the cell-membranes, and the contents of the plant-cells can be utilized only if the cell-wall material is digestible or readily ruptured. It is apparent,

TABLE I. *The Composition of Grasses*[1]

Species	Ash	Reducing substances (as glucose)	Reducing substances after hydrolysis (as glucose)	Total pectin (as Ca pectate)	Total hemicellulose	Cross and Bevan cellulose	Lime (CaO)	Phosphorus pentoxide (P_2O_5)	Protein ($N \times 6.25$)
Cocksfoot (*Dactylis glomerata*)	8·16	3·54	5·51	1·97	18·31	33·20	0·49	0·74	13·99
Meadow-fescue (*Festuca pratensis*)	7·93	1·25	6·25	1·60	18·47	24·07	0·60	0·48	10·63
Chewings fescue (*Festuca rubra*)	8·32	1·01	4·70	0·90	20·70	21·38	0·59	0·51	13·56
Crested dogstail (*Cynosurus cristatus*)	9·08	3·67	13·10	1·02	16·30	23·25	0·32	0·52	10·13
Pampas grass (*Cortaderia Selloana*):									
Sample No. 1	10·55	2·62	3·69	0·86	19·15	40·33	0·47	0·44	9·87
Sample No. 2:									
Leaf portion	8·44	1·73	4·04	1·06	21·44	40·50	0·22	0·24	8·49
Basal portion	7·26	2·60	4·96	1·54	23·51	37·32	0·15	0·22	5·43
Italian rye-grass (*Lolium italicum*)	10·10	2·87	9·05	1·04	17·60	23·95	..	..	..
Timothy (*Phleum pratense*)	8·18	2·25	6·87	1·54	17·22	20·83	0·39	0·53	12·14

[1] With the exception of the pampas grass, the figures for ash, reducing substances, pectin, hemicellulose, and cellulose were taken from Buston [9]; for lime, phosphate, and protein, from the unpublished work of Shorland and McIntosh on the experimental plots of the Department of Agriculture at Kaharoa. All the results are expressed as a percentage of the material dried at 100° C.

Note by R. J. McIlroy: For comparison with grasses analysed by Buston [9] the total hemicellulose in pampas grass samples 1 and 2 was estimated by his micro-method, which involves treatment of the grass with 50 per cent. alcohol containing 1 per cent. sodium hydroxide to remove 'ligno-saccharide' prior to extracting the hemicellulose with 4 per cent. sodium hydroxide.

Recently Norman [10] has shown that this pre-treatment removes hemicellulose as well as lignin. Accordingly, the previous treatment was omitted, the crude hemicellulose obtained being corrected for lignin, estimated by hydrolysis with 72 per cent. sulphuric acid. By this method sample 1 yielded 24·43 per cent. total hemicellulose in the dry material.

Crude hemicellulose	27·13 per cent.	
Lignin in hemicellulose	2·70 ,,	
Therefore total hemicellulose . . .	24·43 ,,	(mean of three determinations)

Loss in alcoholic-alkali treatment $24{\cdot}43-19{\cdot}15 = 5{\cdot}28$ per cent.

therefore, that from the nutritional point of view alone further systematic examination of the cell-wall carbohydrates is needed.

Regarding the structural carbohydrates Table 1 shows that the chief difference between the pampas grass and the common forage grasses lies in the higher percentage of cellulose (37–41 per cent. as compared with 21–33 per cent.). This relatively high percentage of cellulose, together with the large yield of green material (estimated at 50 tons per acre [4]), suggests its use for paper-manufacture. The esparto grass of Spain and Algeria, used for paper-pulp, contains about 45 per cent. of cellulose. Comparative figures for the lignin in the common forage grasses are not available. The determinations of this substance in the pampas grass gave from 16·5 to 18·5 per cent., as compared with 17·9 per cent. given by Norman and Jenkins [14] for grass. Less sugar appears to be present in the pampas than in the other grasses given in the table. As compared with the standards given by Orr [15] for good forage grass, the pampas grass, including the whole of the above-ground portion, or considering the green leaf and basal portions separately, is deficient in lime, phosphate, and protein (CaO, 0·15–0·47 per cent., as compared with 1·10 per cent.; P_2O_5, 0·22–0·44 per cent., as compared with 0·77 per cent.; and protein, 5·43–10·67 per cent., as compared with 18·3 per cent.). When, however, it is considered that pampas grass is intended only as a supplementary fodder, it will be appreciated that the high proportion of carbohydrates is useful in balancing pastures high in protein, whilst the evident palatability and high yield of dry matter (more than 25 per cent.) must not be overlooked. Turnips, for example, although richer in protein (14·4 per cent.), are poor in phosphate (0·14 per cent. P_2O_5), and contain only about 10 per cent. of dry matter, whilst hay from mixed grasses contains 8·75 per cent. protein and 0·38 per cent. P_2O_5 [16].

To account for the evident ease with which such a fibrous plant as pampas grass is digested by ruminants, it has been suggested that as lignin occurs in intimate association with cellulose, these constituting together the greater part of the fibre or cell-wall, the lignin, being itself indigestible, protects the other plant constituents against the action of the ruminant's digestive juices. Where, however, as in pampas, the same amount of lignin is spread over a much larger amount of cellulose, the protective action of the lignin will be diminished and the plant more easily digested.

Summary

Pampas grass (*Cortaderia Selloana*) provides under certain conditions an excellent supplementary fodder for cattle, the coarse leaves being easily grazed. The New Zealand plume grass or toe toe (*Arundo conspicua*), although similar in appearance to pampas grass, is not readily eaten by stock, unless chaffed, on account of the relatively great tensile strength of the leaves.

Pampas grass flourishes on a wide range of soils in New Zealand, being particularly suitable for reclaimed salt marsh. Although plantations suitable for grazing may be established from cuttings, the ideal

method is to plant from seedlings which are spaced 6 ft. apart (1,000 plants per acre). The seedlings, at first in seed-pans, are transferred after selection to a frame or a suitable seed-bed. When they are 6 months old they are ready to plant in the field. The planting should be done in the spring when there is no longer any danger of frost. The plantation should not be grazed until the end of the second year and then only intermittently in breaks, the animals having a run of pasture.

Comparative analytical data show pampas grass to be low in phosphate, lime, and protein, as compared with the common forage grasses. The high proportion of carbohydrate, however, is useful in balancing the high protein-content of young pasture grass.

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Fig. 1. Pampas grass in flower showing male (right) and female (left) flowers at Whangarei Harbour reclamation

Fig. 2. Pampas hedge 5 years old. Dargaville, Northern Wairoa

Fig. 3. Pampas break, McClean's Hauraki Plains, showing eaten out break of pampas and mounds of dead leaves uneaten, also shallow water table

Fig. 4. Two breaks of pampas, Hamilton. Grazed on right of fence during winter, ungrazed on left

FIG. 5. Pampas plantation in flower and ready to be grazed off for the first time, Taupiri

FIG. 6. An acre of pampas in bloom, Taupiri

FIG. 7. Wild seedling pampas on reclaimed salt mud flat, Whangarei

ANALYSES OF SOIL AT WAITAKARURU, HAURAKI PLAINS, AUCKLAND (cf. pages 334–5)

(a) *Mechanical Analyses*

Results are percentages on air-dried soil.

Soil	*Analysis of 'Fine Earth' passing 2-mm. sieve*								*Stones and gravel*	
	Fine gravel	*Coarse sand*	*Fine sand*	*Silt*	*Fine silt*	*Clay*	*Moisture and loss on ignition*	*Loss by solution*		
Loam .	7·9	17·5	1·3	7·8	18·3	12·7	2·9 33·1	1·5	2·5*	Top
Clay .	0·5	1·9	1·0	8·5	34·5	39·2	2·6 12·5	1·3	tr.*	Sub.

* Pumice and organic matter.

(b) *Chemical Analyses*

Results, except*, are percentages on soil dried at 100° C.

Locality	*Volatile matter*			*Total nitrogen*	*1% citric-acid extract, Dyer's method, Hall's modification ('Available plant-food')*			
	**On air-drying*	**At 100° C.*	*On ignition*		*Lime* CaO	*Magnesia* MgO	*Potash* K_2O	*Phosphoric acid* P_2O_5
Top. McClean, Waitakaruru, unmanured. Peaty	31·0	2·9	34·2	0·808	0·063	0·127	0·018	0·048
Sub.	32·9	2·6	12·9	0·275	0·054	0·154	0·025	0·099

Locality	*Hydrochloric-acid extract ('Total plant-food')*				*Lime-requirement % $CaCO_3$*		pH
	Lime CaO	*Magnesia* MgO	*Potash* K_2O	*Phosphoric acid* P_2O_5	*On air-dried soil*	*On soil dried at 100° C.*	
Top. McClean, Waitakaruru, unmanured. Peaty	0·20	0·54	0·36	0·23	1·10	1·13	4·8
Sub.	0·27	1·12	0·51	0·26	0·51	0·52	5·0

INVESTIGATIONS ON BLACK-ARM DISEASE OF COTTON UNDER FIELD CONDITIONS

I. THE RELATION OF THE INCIDENCE AND SPREAD OF BLACK-ARM DISEASE OF COTTON TO CULTURAL CONDITIONS AND RAINFALL IN THE ANGLO-EGYPTIAN SUDAN

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Introduction

IN the following account, which deals with studies of Black Arm, a disease (due to *Pseudomonas malvacearum* E.F.S.) of cotton as it occurs in the Sudan,[1] there must, of necessity, be repeated references to the mode of cultivation practised. A short account of the latter and of the local conditions is therefore desirable.

The principal Sakel-growing[2] area of the Sudan is that irrigated tract called the Gezira, about 100 miles long and 30 miles broad, between the Blue and the White Niles, with its most northerly point about 35 miles south of Khartoum, and held by the Sudan Plantations Syndicate as a concession from the Sudan Government. For administrative purposes this irrigated area is divided into areas called 'Blocks', which are in charge of a Senior or 'Block' Inspector, assisted by one or more Junior Inspectors.

The system of irrigation and the lay-out of the cotton-land may be briefly outlined as follows. From a minor canal is led a channel (called an *Abu Ishrin*), which irrigates an area called a 'Number', 90 acres in extent. This 'Number' is divided into 9 tenancies of 10 acres, each of which is called a *Howasha*, and is irrigated by a minor channel called an *Abu Sitta* leading from the Abu Ishrin. Each howasha is 280 metres long by 150 metres broad, and is divided for watering purposes into 16 *Angaias*, each division being parallel to the shortest side of the howasha: the lay-out diagram (p. 345) indicates these divisions.

Though the tenant is the cultivator of each howasha, the cultural operations are under the control of the Inspector in whose block the howasha lies. The cotton is normally sown about the beginning of August, i.e. about the middle of the rainy season of the Central Sudan, the sowing being made on ridges 80 cm. apart which run parallel to the longest side of the howasha. In each ridge the seed is sown in holes about 30 cm. apart, each hole containing about 8–10 seeds; about 3 weeks later the cotton seedlings are thinned to 3 plants per hole.

The crop-rotation of this area is such that the *previous* season's cotton-land very often lies immediately adjacent to the cotton-land of

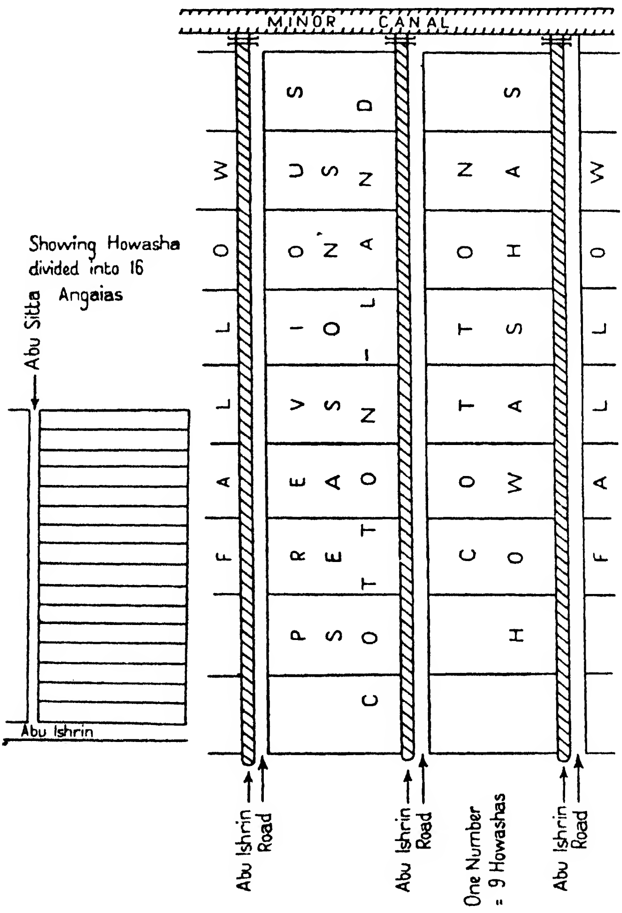
[1] For brevity the word 'Sudan' will be used for 'Anglo-Egyptian Sudan'.

[2] Sakel (a contraction of 'Sakellarides') is the variety of Egyptian cotton grown in the Gezira.

the coming season; this rotation is illustrated in the lay-out diagram below.

In the study of Black-Arm disease it was felt that the laboratory investigations in progress could be very usefully supplemented by observations on cotton plants grown on a field scale under the cultural and

Unit Lay-out of Cotton-land in the Gezira



climatic conditions prevailing in the Gezira. It was hoped that information of the limiting factors of the spread and perpetuation of the disease in the field would be obtained, and would form the basis for a method of control. It was therefore decided that the cotton of certain howashas scattered through the Gezira area should be kept under close observation for the incidence and spread of the disease. These observations were made under the supervision of the author, with headquarters at the Gezira Research Farm, Wad Medani, and this paper embodies the results obtained during the seasons 1932–3 and 1933–4.

The cotton seed sown in the Gezira in both seasons was Egyptian

Sakel, obtained from the Egyptian crop of the previous season. Black-Arm disease is only a minor pest in Egypt (owing to the sowing-period and the rainfall being very different from those of the Sudan), but in order to render negligible any seed-borne infection that might be carried into the Sudan, all the seed was dusted with a proprietary mercurial bactericide called Abavit B. This treatment ensured that any extensive Black-Arm infection appearing on the crop in the Gezira must have come from an extraneous source and was not the result of a seed carry-over.

Season 1932–3

Cultural and rainfall details.—Sowing of the crop began at the beginning of August, but was repeatedly interrupted by the heavy rains that fell during that month.

When the season started it was generally believed that the immediate source of the initial infection was the infective debris which lay on the immediately adjacent old cotton-land. This fallen debris consisted of the leaves, stems, boll-cases, and seed-cotton which remained on the ground after the cotton was cut out. The seed-cotton would be a particular source of danger, because it would give rise during the rains to infected cotton seedlings which would act as a potential source of infection to the new crop, the driving rains, as shown by Faulwetter [1] in America, Massey [2] in Sudan, and Hansford [3] in Uganda, being the vehicle of transmission between these infected seedlings and the new crop. In consequence of this all tenants were given orders by their inspectors to start sowing on the angaia of the howasha *farthest away* from the previous season's cotton-land, and as this sowing was continually interrupted by rains, it is obvious that, in any particular howasha, there would be cotton of varied sowing-dates with a concentration of the earliest sown on the side of the howasha *farthest away* from the old cotton-land.

The general rainfall of the Gezira during the season 1932–3 can be divided into five main periods: 1st period, Aug. 6–8; 2nd period, Aug. 20–1; 3rd period, Aug. 29–31; 4th period, Sept. 5–7; 5th period, Sept. 17–19.

In all these periods driving rains occurred, though, of course, the severity of wind and rainfall varied from place to place.

Details of the observations.—In this season 51 howashas scattered through the Gezira were kept under observation by native observers for the incidence and spread of Black Arm. Observations were made on selected ridges equally spaced through each howasha, and the sowing-date, total plants, and total infected plants per ridge per angaia, were recorded periodically.

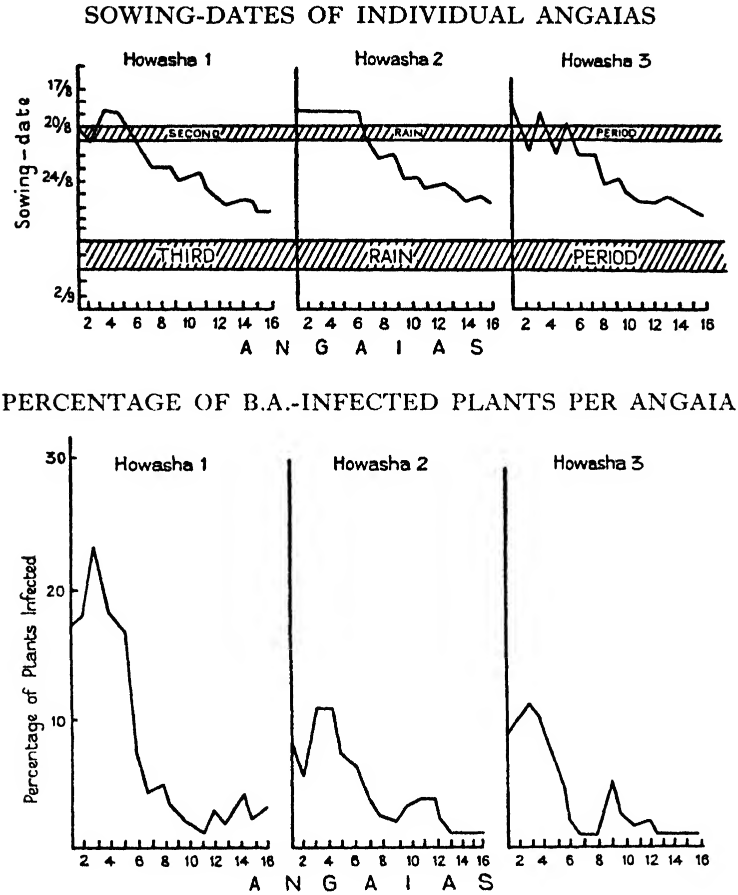
In this and the following season all the selected howashas were normal tenancies leased and cultivated by natives; no special cultural arrangements were made for the investigations, since their object was to determine the incidence and spread of Black Arm under the normal cultivation methods used by the natives in growing a crop of cotton in the Gezira.

Results of the Observations

A. *Relation of incidence of Black Arm to sowing-date.*—It is obvious that the earlier the cotton is sown, the more rains it will be subject to, and since driving rain is the means of transmission of the disease to a

GRAPH I. *Effect of Sowing-Date on the Incidence of Black Arm*

(Observations made Oct. 17–23, 1932.)



Note: The sixteenth angaia lay nearest to last season's cotton-land.

healthy crop, the earlier will the cotton become infected provided there is an immediate source of infection.

This fact was definitely indicated in most of the howashas, where both early and later sown cotton occurred, and is strikingly illustrated in Graph I, where the sowing, beginning on the side farthest from the previous season's cotton-land, was interrupted by the second rain-period. It will be seen that the greatest infection occurs in the earliest sown cotton.

B. *Relation of incidence of Black Arm to proximity of old cotton-land.*—To decide if the immediately adjacent previous season's cotton-land is the main source of infection it is obvious that (*a*) a decision can only be made from a study of howashas that are *completely* sown in 1–2 days, so that all the cotton is above ground in time for the next rain-period, with a consequent avoidance of any concentration of the disease on a particular side of the howasha owing to earlier sowing on that side; and (*b*) that the driving rains must blow from the previous season's cotton-land to the new cotton crop.

Of the total howashas examined only 19 complied with these two conditions. Fourteen of these showed the greatest infection on the side nearest the previous season's cotton-land, and five an irregular distribution throughout the howasha. It is very noteworthy that among these 19 howashas nowhere was the heaviest infection on the side farthest away from the old cotton-land; and subsequent research has shown that where an irregular distribution of the disease occurs in a howasha, it is most probably due to the scattering, during a heavy wind, of infective debris on to the new land before the sowing of the crop.

Graph II illustrates the concentration of the disease on the side nearest the old cotton-land.

The fact that the infection does come from the immediately adjacent old cotton-land and not from some other source is indicated in Graph III. Here we have two howashas, No. 1 having a house on one side, and No. 2 having a howasha of old cotton-land alongside. Both had similar sowing-dates, but it will be noticed that howasha 1 has the greatest infection on the side farthest away from the old cotton-land, whilst the other has the heaviest infection on the side nearest the old cotton-land. The explanation is that the house has protected the nearest angaias in howasha 1 from the infection coming from the opposite old cotton-land, whilst in howasha 2, without this protection, the heaviest infection is on the side nearest the old cotton-land.

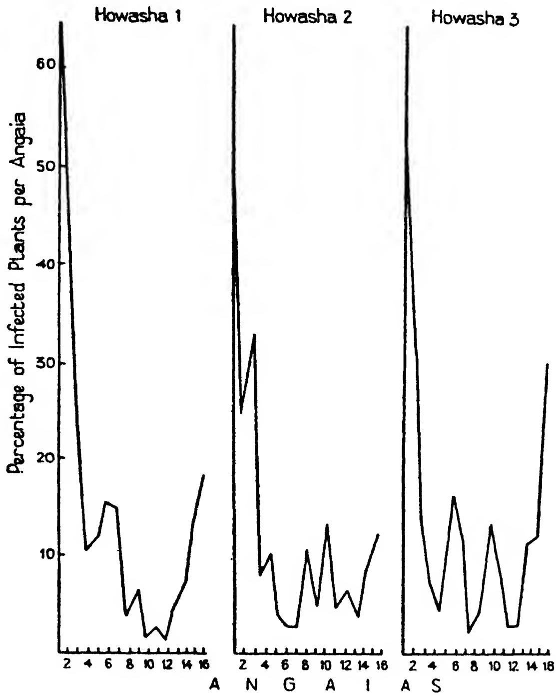
C. *Relation of incidence of Black Arm to rainfall.*—In field observational work by native observers on Black-Arm disease, it has been found safe to reckon that the initial infection of an area of cotton occurred from 12 to 14 days before the symptoms were first observed, and from this it is possible to associate the outbreak in most howashas with a particular rainfall.

From the date of observance of initial outbreak of the disease in most of the howashas under observation it appeared that the heavy rains of Aug. 29—31 were responsible for the main infection.

This is strikingly indicated in Graph IV, where the relation between the percentage of angaias sown and the number of howashas reporting initial infection is shown. It will be noticed that the major portion of the sowing occurred during the period Aug. 16–24, so that all this cotton would be above ground at the time of the third rain-period (Aug. 29–31). That this rain was responsible for infecting the cotton of this sowing-date is indicated by the fact that 12–14 days later (i.e. Sept. 11–14) the largest number (15 out of 28) of reports of initial outbreak was received.

The total number of outbreaks was small compared with the number of howashas under observation. This is due to the fact that not all observers observed equally well; only 28 were considered to have reported the disease sufficiently early for it to be described as an initial outbreak.

GRAPH II. *Effect of the Proximity of Last Year's Cotton-Land on the Distribution of Black Arm*



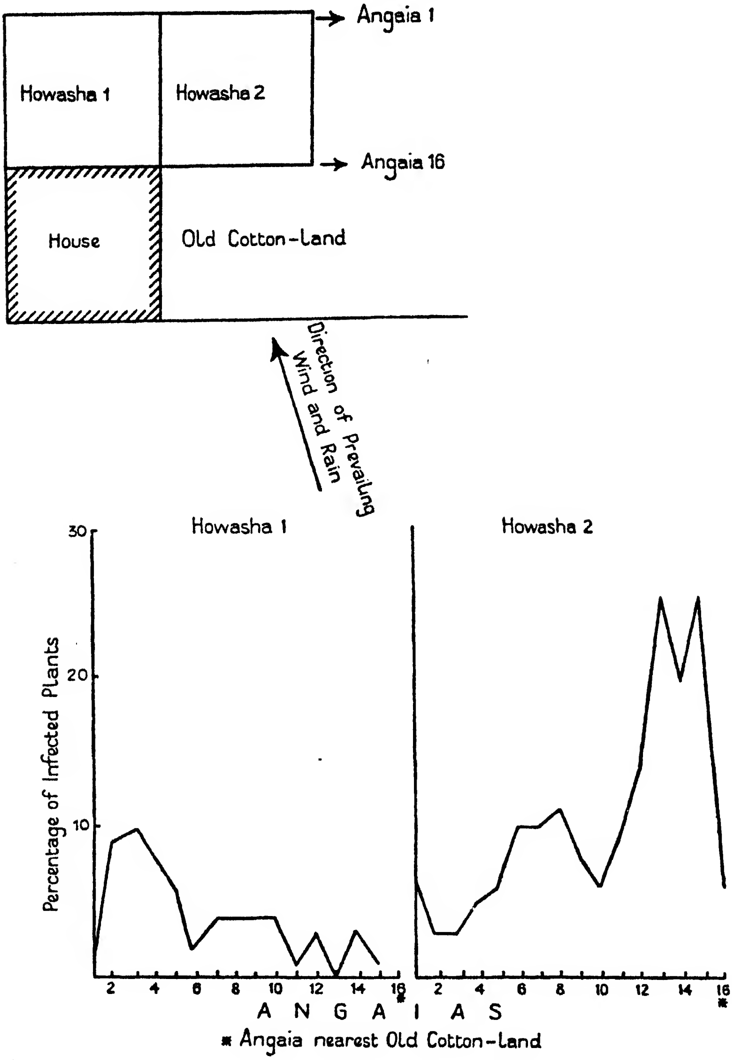
Note: In this case the sowing of the whole of howashas 1 & 2, and of the 15th and 16th angaias of howasha 3 was done on one day (Aug. 19). The remaining angaias in howasha 3 were completed on August 20.

In each case angaia No. 1 lies next to last year's cotton-land.

To summarize these data, and also to determine statistically if the adjacent old cotton-land was the main source of infection, or whether sowing-date was all important, a collection of data per howasha was made in which the sowing-date, percentage of infected plants per angaia, and the number of the angaia (i.e. indicating the position in the howasha) was known or could be interpolated. The number of angaias from which these data could be obtained totalled 384, and for the purpose of this examination angaia No. 1 was always the one nearest the previous season's cotton-land, and therefore angaia No. 16 the one farthest away from the old cotton-land.

The observations of percentage of infected plants present in these angaias were made between Oct. 5 and 15, and thus the amount of

GRAPH III. *Carry-over of Infection from the old Cotton-Land*



Black Arm present would be more or less stationary, as the immediate effects of the rain would have appeared by that date.

From these data it would thus be possible to find out if there was any correlation between—

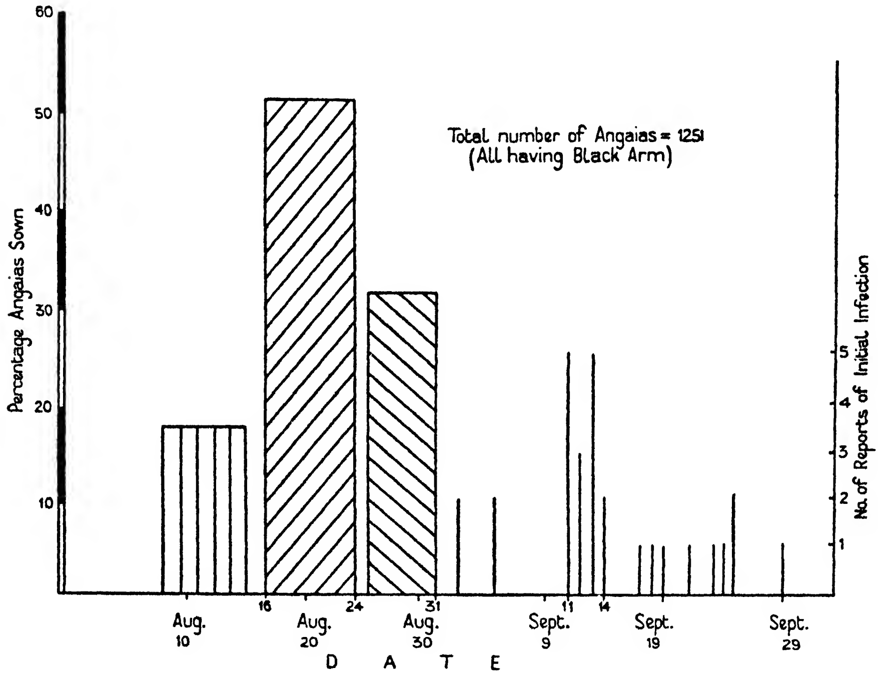
(*a*) position of angaia in howasha and percentage of Black Arm;
(*b*) position of angaia in howasha and sowing-date;
(*c*) sowing-date and percentage of Black Arm.

The above-mentioned data were submitted for statistical analysis, and gave the following results:

The partial correlation between the percentage of infected plants and angaia number (i.e. position in howasha), eliminating the effect of

sowing-date, is negative, but not significant. The probability is P = 0·2 to 0·1, i.e. the likelihood of this occurring by chance is between 1 in 5 and 1 in 10 cases, against 1 in 20 required for established significance. Hence one can safely conclude that there is a definite indication that Black Arm is worst nearest the old cotton-land, but it cannot be considered as established from these results alone. The ordinary correlation

GRAPH IV. *Relation of Amount of Cotton sown to Number of Reports of Initial Infection*



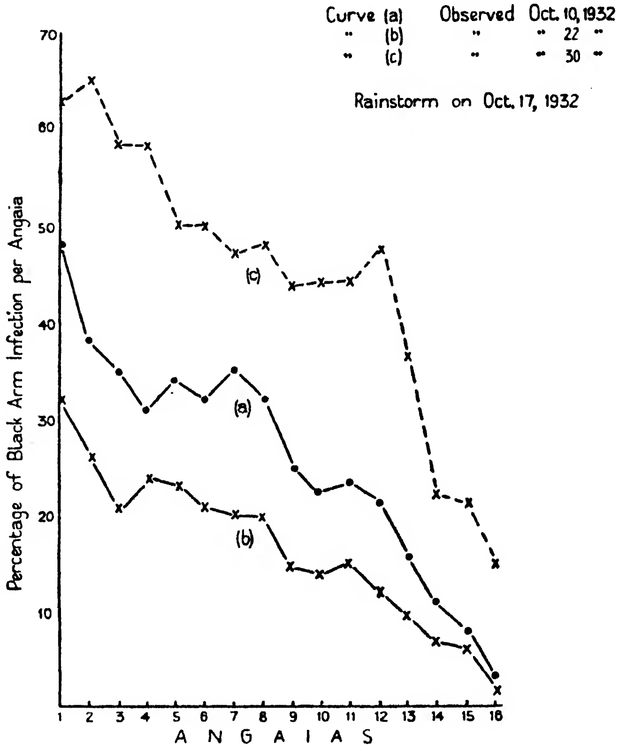
coefficients (for 384 observations) are: (1) *Percentage of infected plants and sowing-date* = 0·319 (highly significant). (2) *Percentage of infected plants and angaia number* = 0·051 (not significant). The incidence of Black Arm as a whole is not significantly related to angaia number, but as the ratio is positive there is a slight indication that the disease increases with distance from the old cotton-land (i.e. in the angaia which, in this season, happened to have more early-sown cotton). (3) *Sowing-date and angaia number* = 0·363 (highly significant), indicating, as has already been stated, that in the 1932–3 season much more early-sown cotton occurred in angaias farthest from the old cotton-land.

Summarizing, the slight indication of increased Black Arm with distance from the previous season's cotton-land is eliminated when sowing-date effects are considered, and, in place of it, there is a stronger indication of increased Black Arm nearer the old cotton-land. The significance of these indications, however, is not established.

Thus, as already stated, the evidence that the previous season's cotton-land is the main source of infection has been very considerably obscured in the season 1932–3 by the large amount of early sowing occurring on the side most distant from the old cotton-land.

D. *Relation of rainfall to the spread of the disease.*—Once the disease has arrived in the new crop the rate of spread will obviously depend on

GRAPH V. *Spread of the Disease due to a Particular Rainstorm*



Last season's cotton-land is next to Angaia 1.

the frequency and severity of the rainstorms. This was very clearly indicated in most of the howashas under observation and is illustrated in Graph V.

The curve (*a*) shows the percentage of infected plants on Oct. 10, 1932. An observation on Oct. 22, 1932 showed that the percentage of infected plants had *decreased*, owing presumably to the shedding of the infected leaves on some of the plants, in which case these plants would be classed as healthy (curve (*b*)). A rainstorm occurred on Oct. 17 and an observation on Oct. 30 (by which time the effects of this rain would be apparent) showed an increase in the percentage of infection (curve (*c*)). This graph also shows another striking case of the concentration of the infection on the side of the howasha nearest the previous season's cotton-land.

Season 1933–4

Cultural and rainfall details.—The sowing of the cotton under observation began on Aug. 1; owing to the satisfactory distribution of the rainfall, 67·7 per cent. was sown by Aug. 15 and 96·2 per cent. by Aug. 24. No special arrangements were made in this season for the sowing to begin on the side of the howasha farthest from the previous season's cotton-land.

The rainfall of the observational area during August and September may be roughly divided into four main periods during which a rainfall (more or less heavy) occurred in all areas under observation.

These periods are: (1) Aug. 3–6 (generally a small rainfall); (2) Aug. 20–2; (3) Aug. 27–31; (4) Sept. 9–12, and, in a number of the areas, a 5th period occurred on Sept. 19–22.

It is noteworthy that for a similar period in 1932 the rainfall could be divided into main periods of which the dates very closely correspond to those of this year.

In 1932 the main periods were: (1) Aug. 6–8; (2) Aug. 20–2; (3) Aug. 29–31; (4) Sept. 17–22.

It must be understood that the quantity of rain and the severity of wind during any period varied greatly from area to area; but there seemed to be a certain consistency in the date at which the heavier rain fell in the various areas under observation.

Details of the observations.—From the experience gained during the last season, it was felt that better and more accurate results would be obtained if intensive observations were confined to a few howashas, instead of the large number of the previous season. More intensive supervision could be given to the work, and it was hoped that the results would yield a more detailed account of the incidence and spread of the disease. In consequence, 16 howashas scattered through a badly infected area were kept under observation during this season. Observations were made on each of a total of 18 ridges, i.e. 6 groups of 3 ridges equally spaced through the howasha, and the sowing-date, total plants, and total infected plants were recorded periodically per ridge per angaia. It was thus possible to make a plan of the position in the howasha of the initial infection and its subsequent spread.

Results of the Observations

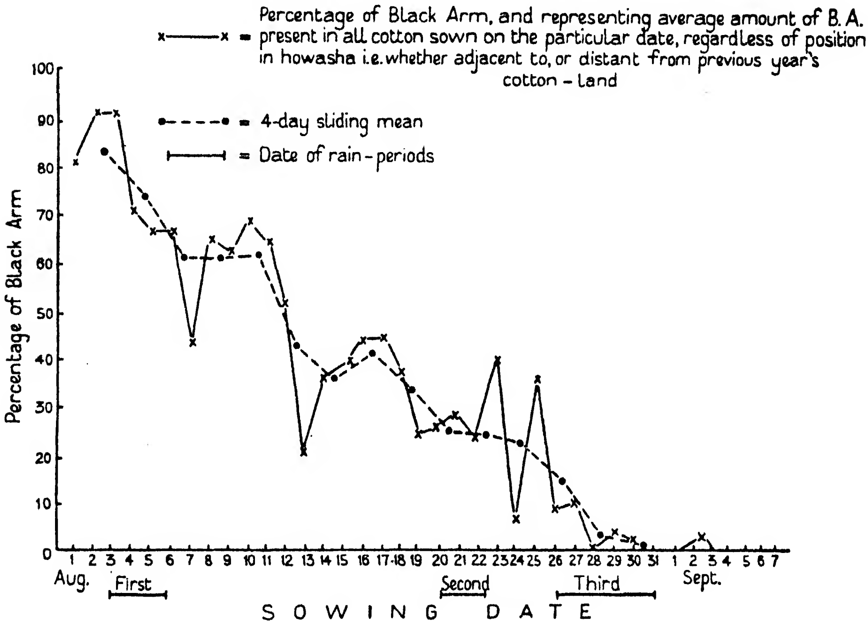
A. *Relation of percentage of Black-Arm infection to the sowing-date and rainfall.*—Given the sowing-date and the percentage of infected plants in the particular angaias having the same sowing-date, it was possible to construct a graph to show the relation between these two factors (Graph VI).

The date chosen for observation of the quantity of Black Arm in the angaias of various sowing-dates was about Oct. 15. The time between this and the date of the last rain was sufficient to allow its immediate effect to be apparent and recorded.

The curve showing the actual relation between these two factors indicates very strikingly the decrease in the amount of infection with

increasingly late sowing-date. The decrease indicated in this curve can be due either (*a*) to lack of infective material on the previous season's cotton-land, (*b*) to diminishing rainfall, (*c*) to climatic conditions unfavourable to the development of Black Arm, or (*d*) to the decrease in the quantity of cotton sown, with consequent unreliability of average figures obtained.

GRAPH VI. *Relation of Percentage of Black Arm to Sowing-Date*



Climatic conditions were suitable for the spread of Black Arm up to Oct. 15, in fact up to the end of November and possibly later, and observations had shown that the quantity of infective material on the previous season's cotton-land was considerably greater at the end of August and early September than during the first half of August. Most of the crop was sown from Aug. 9 to 15 and more was sown after Aug. 15 than before Aug. 9. There is thus an evident relationship between the amount of infection and diminishing rainfall, and the sowing-date of the cotton only affects the quantity of Black Arm in so far as the later sowings are subject to less rain.

The dotted curve is that of a four-day sliding mean and indicates the general trend of the relation between the two factors.

The definite 'steps' into which the decrease in infection falls are noteworthy: one occurs between Aug. 7 and 11, another between Aug. 13 and 19, and another between Aug. 21 and 25. It would seem that all cotton sown between the dates of these successive 'steps' had a similar amount of infection, and it is very striking to find that each step of sustained infection is followed 9–13 days afterwards by a heavy rain-period. It would appear that the cotyledons and leaves of the young

cotton plant first attain a condition in which they can become infected when the plants are about 11 days old, and not less than 9 days old in any case.

The existence of this 9–13 day period was also suggested by some of the records obtained in the previous season, i.e. 1932–3.

B. *Relation of spread of Black Arm to rainfall.*—A particular feature of the spread of the disease in the cotton of this season was the correlation between rapid increase and the occurrence of driving rains. Of the 16 areas under observation, 5 showed a rapid increase of the disease, and of these 3 had late driving rains. No information was available as to the type of rainfall in the remaining two. Nine areas recorded a slow increase of infection, and in every case this can be associated either with very slight late rains or with the complete absence of them. In some howashas it has again been possible to associate a particular increase in disease with a particular rainfall.

C. *Relation of incidence of infection to proximity of the previous season's cotton-land.*—Out of a total of 15 howashas having last year's cotton-land immediately adjacent to the new cotton, 10 areas showed initial infection on the side of the howasha nearest the old cotton-land, and in only one of these would it be expected that the initial infection would be on that side owing to the earliest sowing having occurred there.

Of the five areas showing either an irregular distribution in the howasha or initial infection on the side farthest from the old cotton-land, one was a probable case of infection by blown infective debris; three can be definitely associated with 'adverse' wind direction, i.e. blowing from a direction contrary to that from the old cotton-land to the new cotton; and there remains only one area for which no adequate explanation could be found for the irregular distribution of the disease.

Summary of the Results of the Two Seasons

(*a*) The infective debris on the immediately adjacent cotton-land of the previous season appears to be the main cause of an outbreak of the disease in the new crop.

(*b*) Provided that an adequate source of infection is present on this immediately adjacent old cotton-land, the sowing-date appears to be a major factor in governing the earliness of the infection.

(*c*) Since driving rains are the vehicle of transmission of the disease from the old cotton-land to the new, the severity and frequency of these must be a very important factor in determining the final severity of the disease.

(*d*) As the limits of the sowing-date of the cotton are narrow, for economic reasons, it is obvious that the only effective way to control this disease is to remove or render innocuous the infective material on the old cotton-land.

Research is now concentrated on this aspect of the problem.

Acknowledgements

I have to acknowledge my indebtedness to Mr. R. E. Massey, Government Botanist, Sudan Government, and Head of the Plant Pathological

Staff, for help in this work; to Dr. F. Crowther, late Plant Physiologist, Sudan Government, for assistance in the statistical analyses; and to Mr. M. A. Bailey, Director of the Agricultural Research Service, under whose direction these researches were made.

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VILLAGE WASTE

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1. THE loss that occurs in the almost complete failure to utilize the manurial value of habitation wastes, and the possibility of preventing this waste by the adoption of some kind of activated-compost system, such as that suggested by Fowler, has attracted a good deal of attention lately [1, 2, 3, 4]. This article describes an attempt to make use of local village refuse in this way in order to discover its possibilities.

2. Under the system that obtains at present all rubbish, whether house garbage or street refuse, is collected at intervals by a contractor, who employs his own men and carts, and removed to a dumping-ground, at some little distance, where it is supposed to be buried in pits or trenches. The cost of trenching, covering, and levelling the ground after filling, is borne by the village authorities. Practically no manurial value is obtained in this way, and except for its occasional use for filling up depressions, the disposal of this refuse is regarded as an expensive nuisance. One full-time labourer, or 26 man-days a month, was being employed in the present instance.

3. Arrangements were made to have this material delivered to a suitable locality on the College Farm.[1] Besides the material brought by these carts, a certain amount of estate rubbish was delivered by the College lorry, consisting of hedge-trimmings, refuse, and house garbage. The arrangements at this depot were made with a view to ensure complete aeration and thorough inoculation of the raw material with partially rotted material. All new material was mixed immediately on arrival with its own bulk of material which had been decomposing for a week. The heaps were maintained at a standard width, 3 ft., and at a height, which varied with the season, from 3–4 ft., being higher in the dry weather, when aeration was better. The moisture-content of the material varied, and when the rainfall was insufficient water had to be added as the heaps were made up, to keep them moist enough to decompose.

4. The arrangements made were as follows (Fig. 1): On either side of a central track, 12 ft. wide, heaps $5 \times 3 \times 3$ ft. were made. Each complete heap was allowed to remain for a week, when it was doubled. After another week it was divided, and half the heap was moved outwards to a second heap. At the end of the third week, these half-sized heaps in the second row were completed. The following week the process was continued to a third heap, from which the material was subsequently removed, half a heap at a time, to a dump where it was stored in bulk, and where a further slow process of decomposition occurred. After six weeks the process became continuous, and each working-day of the week the requisite number of third-row heaps were divided and half of

[1] As the authorities considered that this entailed a longer lead for the cartmen employed, they decided that a sum of 6 cents (3*d.*) a cart should be paid to the contractor for the extra work involved. It was not thought worth while contesting this charge, which was, in the writer's opinion, unjustified.

each removed to the main dump: they were then made up to full size from the second-row heaps. The second-row heaps were made from the first-row heaps, and the half of each first-row heap left was thoroughly incorporated with an equal quantity of raw refuse.

5. The system worked well. The loads were dumped right on the spot where they were wanted, and there was a minimum of carting. It is, of course, true that such a depot occupies a considerable area (Fig. 2), but this is unavoidable, as if the heaps are made too large, they do not

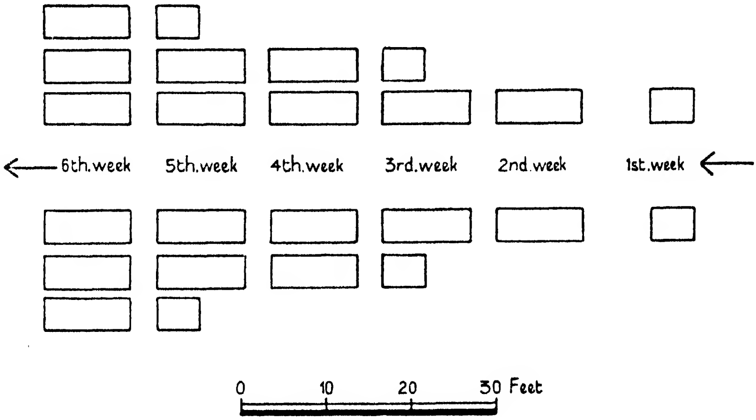

FIG. 1.

decompose properly. The material soon became thoroughly impregnated with fungal mycelia, temperatures rose very rapidly, and decomposition was pretty thorough.

6. Work started in December 1934, and the experiment was carried on uninterruptedly until the end of October 1935, a period of eleven months. The table below shows the quantities received, and the amount of manure made:

	Received						*Sent out Cart-loads (Finished compost)*	
	Cart-loads of rubbish		*Lorries (estimate)*		*Total cart-loads*			
	No.	*Cost of carting*	*No.*	*Equiv. in carts*	*No.*	*Weight (estimated) tons*	*No.*	*Weight Actual tons*
		$						
Dec.	201	12·06	13	26	227	80	22	10·00
Jan.	228	13·68	13	26	254	89	..	..
Feb.	225	13·53	20	40	265	92	1	0·30
March	275	16·53	20	40	315	110	1	0·30
April	265	15·81	20	40	305	106	19	5·45
May	214	12·87	32	64	278	97	20	8·38
June	182	10·95	20	40	222	77	128	57·95
July.	209	12·54	20	40	249	87	19	10·65
Aug.	199	11·97	20	40	239	83	5	2·50
Sept.	196	11·76	20	40	236	82	..	..
Oct.	201	12·06	22	44	245	85	23	14·00
	2,395	143·76	220	440		988	238	109·53

7. It was estimated that at the end of October there were about 50 tons of partially complete manure still at the depot.

8. In considering these figures, it has first to be noted that all the

material received did not go into the dumps. There was a large proportion of inert material in the shape of tins and iron utensils, bottles, whole or broken, of all sizes, and india-rubber shoes. Random weighments of this inert material showed 960 lb. collected from eight carts, which, at 7 cwt. to the cart, is over 15 per cent. Most of this material had to be picked out and buried in deep pits. This was expensive, for it implied a considerable and increasing lead. It was not expected that there would be such a large number of tins, but tinned milk is in regular use,

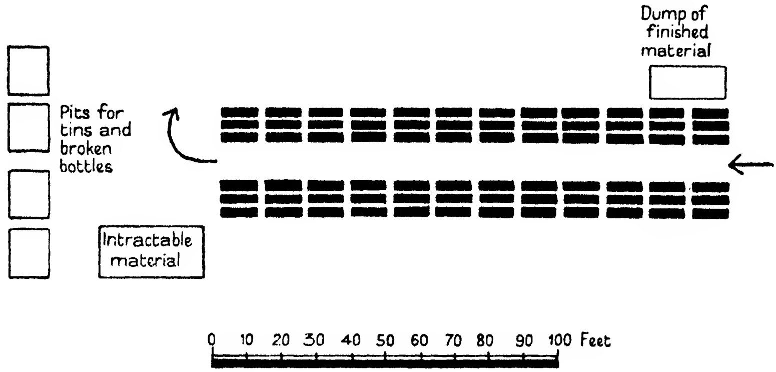

FIG. 2.

and other tinned material enters largely into the diet of the West Indian. It was not possible to remove the broken glass completely, and several casualties due to cut feet have occurred among the field labourers working barefooted in the lands manured with this material. In addition, there was what was called 'intractable' material, such as coco-nut husks, palm fronds, and large branches. This was removed to a heap (Fig. 2), which was turned over twice a year, when any partially rotted material could be collected and incorporated into the regular heaps.

9. After the removal of this useless material, the residue went into the heaps for fermentation. This residue contains such a varying amount of moisture, that it is very difficult to make out any accurate balance-sheet of incomings and outgoings. The samples analysed in August gave from 29 to 40 per cent. of moisture, whilst in March some analyses showed as little as 11 per cent.

10. The problem is further complicated by the actual loss of material that occurs during the process of composting, which may be considerable if this is continued for long. Below are the measurements taken of some heaps in the depot which were originally all similar in size:

Heaps one week old: $10 \times 3{\cdot}25 \times 2{\cdot}5$ ft. $=$ $81{\cdot}2$ cu. ft.
Heaps two weeks old: $10 \times 2{\cdot}5 \times 1{\cdot}5$ ft. $=$ $37{\cdot}5$ cu. ft.
Heaps three weeks old: $10 \times 2{\cdot}25 \times 1{\cdot}25$ ft. $=$ $28{\cdot}1$ cu. ft.

This reduction in size is accompanied by some increase in density, though probably not enough to make up for the loss, and of course the heaps may be losing moisture. The average volume-weight ascertained for such compost was from 20 to 30 lb. per cubic foot.

11. The question of water is important from the standpoint of expense. Water was added, though probably rather more than was necessary. An inspection of the heaps in June gave the impression that they were too dry, and an experiment was carried out in which the heaps were thoroughly soaked each time they were turned over. Half the number of heaps were allowed to remain a fortnight, instead of the usual week, in each stage, so that the stages of manufacture were not completed for eight weeks: the other half was turned weekly. This was to ascertain whether a longer period of manufacture would give a better final product. Two months after the start[1] the heaps were sampled, and were compared with compost which had been made in the ordinary way, i.e. by moistening occasionally.

	Soaked and turned at 14-day intervals	*Soaked and turned at 7-day intervals*	*Not soaked and turned at 7-day intervals*
Non-analysable matter .	32·7	21·5	34·7
Water . . .	29·9	40·6	27·4
Ash	29·7	29·0	30·9
Organic matter . .	7·7	8·9	7·0
Nitrogen . . .	0·256	0·294	0·268

It appears that the need for water to promote decomposition is likely to be exaggerated.

12. The quality of the manure may now be considered. Sampling was not easy, for it was found that even in the finished material there were many small pieces of tin, wood, glass, iron, and stones, which had to be removed before the manure could be analysed, and this foreign matter, where it was separately weighed, was found to be considerable, averaging 29 per cent.

Analyses of Village-Refuse Compost

	June 1934	*March 1935*	*June 1935*	*April 1936*		*Average*
	1	2	3	4	5	6
Non-analysable matter (of no manurial value) .	(25)	(25)	35	33	19	28
Moisture . .	24	16	27	25	34	25
Ash . . .	33	18	31	28	30	28
Organic matter .	18	40	7	15	17	19
Percentage on oven-dry material (of complete sample)						
Nitrogen . .	0·64	1·11	0·27	0·71	0·86	0·71
Phosphoric acid .	..	..	0·18	0·38	0·53	0·36
Potash . .	..	..	0·23	0·76	0·88	0·62

[1] The rainfall during this period was as follows: June, 3·79; July, 7·75; August, 13·74 inches.

For comparison a few other analyses are quoted:

	Average Ceylon street-refuse compost [5]	*Maize-straw compost*	*Adco from cane-trash*	*Average pen manure Trinidad*
Non-analysable matter (of no manurial value)	8	..	..	..
Moisture . . .	46	68	74	75
Ash	34	10	10	16
Organic matter . .	12	22	16	9
	Percentage on oven-dry material			
Nitrogen . . .	0·62	..	..	1·89
Phosphoric acid . .	0·40	..	..	1·25
Potash . . .	0·47	..	..	2·13

It will be noticed that there is a wide range of variation in the quality of the village-refuse compost, in spite of care in taking the samples. No. 3 is particularly poor; it was reported at the time that the cartmen were bringing in very poor material in their endeavour to earn as much as possible. Nos. 4 and 5 are taken from manure now being made in exactly the same way by the Government nurseries at St. Augustine. The cartmen are not paid by the cart, and the material they bring is undoubtedly better; and water is laid on. The high figure for non-analysable material in No. 4 is due to the presence of a large stone.

The quality of the compost is, however, not very high, though it is noticeably drier than most of the manures with which it might be compared. The total organic matter is low, due in the main to the very high proportion of ash, largely the earth swept up with the rubbish. A great many of the roads in the locality are oiled, and this figure is higher than was expected. This extraneous matter adds a great deal to the cost of handling and carting, besides slowing down the fermentation process.

13. The value of the manure, based purely on its manurial ingredients, is calculated below:

	Per cent. average	*Value per unit*	*Value*
			$
Nitrogen . .	0·53	1·50	0·80
Phosphoric acid .	0·21	1·00	0·21
Potash . .	0·46	1·47	0·67
Total . .			1·68

Its real value, however, is considerably higher than this, for it is an organic manure, and opinion to-day is more than ever in favour of bulky organic manures, supplemented, where necessary, with inorganic manures, as a means of maintaining soil condition and raising healthy crops. Considerable herds of cattle are kept in Trinidad to assist in turning cane-trash and similar substances into manure, so convinced are the planters of the need for organic manures. If it is accepted that such a manure is necessary, and the writer is convinced that it is, on the soils of

the College Farm, then this system indicates a way in which it can be obtained.

14. The cost of making this compost is as follows: The routine work at the depot consists in turning over a certain number of heaps: incorporating the new material in the first-row heaps: removing the completed half-heaps to the dump: carting away the inert material and digging pits to receive it; and carting water during the dry weather. It was calculated, after a few weeks' trial, that the necessary labour would amount to about 75 man-days a month, at a cost of about \$35·00, or \$380·00 for the eleventh-month period. Animal power was estimated at \$70·00 a year —a total of \$450·00: actually the total cost for labour for the period was \$481·00.[1] For this sum a total quantity of rather over 150 tons of compost was made, at a cost therefore of \$3·20 a ton. This seems excessive, but could be reduced if work was carried out on a larger scale.

15. There is another aspect from which this system must be examined, namely, whether it satisfies sanitary standards. One of the main troubles in the disposal of habitation wastes is the breeding of flies. It is claimed by some advocates of this composting system that the heat developed in the heaps—temperature about 65° C.—is sufficient to destroy fly larvae. This was not found to be the case, but there is no doubt that the nuisance from this is very much reduced, and that there need be no complaint on this ground, or on the ground of objectionable smells.

16. Some experiments were carried out [6] to ascertain what emergence of flies might be expected from the heaps. After the heaps had been built up they were left exposed for varying periods of time, up to a week, when they were covered with fly-proof cages. These were left on until emergence had ceased, which happened in about 3 weeks from the time the heap was built. The table below shows the total number of flies and the total number of house-flies that emerged from these differently treated heaps. The figures are the average for each of two heaps similarly treated.

Treatment	*Total Flies*	*Musca*
Covered at once . . .	1,328	606
Covered after 24 hours . .	636	482
Covered after 3 days . .	358	253
Covered after 7 days . .	326	307

17. These figures indicate that the material is fairly heavily infected when it reaches the depot, but that it does not form an attractive *nidus* for oviposition, once it has been made up into a compost heap. What the experiments have shown is that fly larvae can stand much higher temperature than was imagined. Most of them are to be found, naturally, near the surface of the heap, but they have also been found well inside a heap which was registering 70° C.

18. The system thus satisfies all requirements except that of cost, and this, it has been suggested, would be reduced, if work was carried out on a larger scale. The authorities would be saved the expense of the

[1] The contractor was paid \$144·00, but this is not taken into account as it would not have to be paid in ordinary circumstances.

labour which they now have to employ to bury the refuse, and this saving would reduce the cost of the compost. In this experiment the method of payment by carts also caused a certain amount of sharp practice on the part of the cart-drivers, who tended to bring short weight and poor material.

19. The real trouble is, however, the poor quality of the raw material, to which allusion has already been made. Civilization has brought the tin and the bottle, and increased considerably the difficulty of disposing of habitation wastes. It has been suggested that the material with which the experiments were carried out was not typical, but in Trinidad, at any rate, it is probably fairly representative. Conditions in the East, where most work has been done on this problem, are of course very different. Many castes in India use leaf plates, fresh for each meal, a practice which is bound to increase the organic matter in the refuse. Tinned food is rarely eaten, and bottles of all kinds are much too valuable to be thrown away. Consequently there is much less inert matter, and less cost in manufacture. In Trinidad a method would have to be devised to eliminate some of this extraneous matter before composting was begun.

20. An experiment was carried out at the request of the sanitary authorities in a neighbouring village, where there was an outbreak of enteric. Here the raw material was village rubbish, with a preponderating quantity of cow-pen manure, which, owing to the danger of fly infection, it was thought desirable to remove at short intervals. This material fermented vigorously, and produced a far better compost than that obtained at the College, under the conditions described above.

Summary

21. The preparation of compost from village rubbish in Trinidad is shown to be feasible, but not economic. The high proportion of inert and often objectionable material increases the cost of manufacture and reduces the quality of the finished product. Evidence is given that the system outlined satisfies sanitary requirements.

Acknowledgements

The analyses quoted were all made in the Chemical Department of this College by the courtesy of Professor Hardy. The Reader in Agriculture, Mr. Paterson, supervised the experiment in the absence of the author.

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NOTE *by* RUDOLPH. D. ANSTEAD

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This experiment at the Imperial College of Tropical Agriculture was instigated at my suggestion during my visit to Trinidad in January 1934, and so I may perhaps be permitted to make a few comments.

Professor Wood has carried out a most valuable and instructive piece of work and thoroughly demonstrated the possibilities of this method of dealing with village refuse, usually regarded as an expensive nuisance. The College was handicapped in several ways, and I am convinced that it is work for a municipality and not for a farm. A farm can deal with its own waste material, but is not really suited for dealing with municipal refuse, unless this is delivered to it free of cost and reasonably free from useless material. A public body must dispose of its refuse in any case, and the whole question centres round whether it is possible to *utilize* such material for the benefit of agriculture, and not merely *dispose* of it. The usual disposal methods employed are as a rule costly, insanitary, and unsatisfactory. The method recommended provides for satisfactory disposal, and at the same time gives a product which has some monetary value, however small. In South India, where conditions are admittedly more favourable than they are in Trinidad, the monetary value of the compost is often found to cover the whole cost of the process, and thus reduce the rates.

The cost of the process at the College has been high, but were it carried out by the municipality this would be considerably reduced, and if done on a large scale still further savings could be effected. The main difficulty appears to be the unsuitable nature of much of the refuse, and this was intensified in this experiment by the system of collection employed. In the hands of the municipality the difficulties could be reduced by separate collection of materials like bottles, tins, and boots, and there would not be the temptation for cartmen to bring unsuitable material merely to earn more money. Too much notice should not therefore be taken of the cost of manufacture at the College under the conditions imposed on them. What is of importance is the fact that Prof. Wood says that 'the system worked well'.

The necessity for watering the heaps is, I think, apt to be exaggerated, and except, perhaps, during a prolonged dry spell it should be quite unnecessary.

In considering the economics of the process other factors should be taken into consideration besides the simple formula:

$$\text{Cost of manufacture} = \text{Value of resulting compost based on its nitrogen-content} \pm X,$$

where X is perhaps a loss. On this side of the equation credit must be allowed for sanitary advantages and savings in the health departments, and the fact that material is being produced which can be utilized for agricultural purposes. The compost made at the College was very variable in quality, but this could probably be corrected by better methods of collection of the waste material. Even so, however, it has very considerable manurial value. These activated composts have proved to be very valuable fertilizers. The plant-food in them is readily and quickly available, and their value must not be calculated on their nitrogen-content only; it really consists in the humus-content, and the effect of this on the health of the crop. As Prof. Wood says, if it is accepted that organic matter is necessary, then this system does indicate a way in which it can be obtained.

The experiment at the College Farm has indeed indicated the lines which should be followed, and it appears to me that with this information before them a public body like a municipality should be able to devise a method of dealing with its waste products on biological lines which would prove economical and convert such waste into wealth, as is being done in many other countries.

(Received June 15, 1936)

A MANURIAL EXPERIMENT ON BANANAS

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In a previous note[1] attention was drawn to the need for manuring bananas in Trinidad, if any profit was to be obtained. A more detailed trial has now been made to see what effect follows from the addition of potash, or potash and phosphoric acid, to a general organic manure, on the quality and the quantity of the banana crop. The variety used was the Dwarf Cavendish, because the land was affected with Panama disease, and although this banana is not grown for export, the 'count' system of valuation was adopted. The 'count' bunch is one of 9 hands or over. Nothing extra is given for bunches containing more than 9 hands; an 8-hand bunch counts only as ¾ of a bunch, and a 7-hand, if accepted, is only a ½-bunch. Bunches containing less than 7 hands are generally not accepted.

Lay-out.—The experiment was carried out in Field 33 on the College Farm. The three treatments were replicated four times, the plots being randomized in each block. Each plot was square and comprised 16 trees, which were all numbered. Shallow trenches were dug between plots, to assist in demarcating them. The trees were planted 10 ft. apart each way (435 to the acre), so that each plot was 1,600 sq. ft.

Soil.—The soil is a detrital sandy loam, somewhat reworked by stream action, derived from quartz-schists which comprise the main rocks of the Northern Range of Trinidad. Its content of coarse and fine sand is about 50 per cent.; it is slightly alkaline in reaction, and contains only about 1·5 per cent. of organic matter in the surface 6-inch layer. Available potash is notably deficient (35 p.p.m.K_2O) and available phosphate slightly deficient (30 p.p.m.P_2O_5).

Treatments.—The standard plots were manured as follows:

Treatment I.

August 1932, 100 lb. pen-manure per stool (20 tons an acre).
July 1933, pulverised limestone at 6·6 tons an acre.
October 1933, 100 lb. pen manure per stool.
October 1934, 2 lb. sulphate of ammonia per stool (8 cwt. an acre).
January 1935, 2 lb. sulphate of ammonia per stool (8 cwt. an acre).

Treatment II. As above, but *in addition*, muriate of potash was given on the following dates: Aug. 1932, 1 lb., Oct. 1933, 1 lb., Jan. 1934, 1 lb., Oct. 1934, ½ lb., Jan. 1935, ½ lb.

Treatment III. As No. II, but *in addition*, superphosphate was given: Aug. 1932, 2 lb., Oct. 1933, 2 lb., Jan. 1934, 2 lb., Oct. 1934, 1 lb., Jan. 1935, 1 lb.

Results

The following are the yields obtained from the plots:

[1] *Tropical Agriculture*, 1932, **9**, 352.

TABLE 1. *Yields of 'Count' Bunches*

(Totals for five years)

Treatment	*Block 1*	*Block 2*	*Block 3*	*Block 4*	*Total*
Basic	15·25	26·75	25·75	33·75	101·50
+Potash . . .	44·25	37·00	41·75	47·75	170·75
+Potash and phosphoric acid	27·00	27·25	37·75	48·75	140·75
	86·50	91·00	105·25	130·25	413·00

Significant difference between totals, 36·7 bunches ($P = 0{\cdot}05$).

The gain due to the use of potash is significant at the 1 per cent. point. There is apparently no benefit from using phosphoric acid; and there is a strong probability that its use has actually depressed the yield.

TABLE 2. *Yields of 'Count' Bunches per acre*

Treatment	*For 4 plots (5 years)*	*Per acre (5 years)*	*Per acre per annum*
Basic (N)	101	691	138
Basic with muriate of potash (N+K) .	170	1,162	232
Basic with muriate of potash and superphosphate (N+P+K)	140	958	192

The cost of the additional dressings of manures and the value of the increases in yield obtained from them are shown in Table 3:

TABLE 3

	Increase bunches	*Value \$*	*Dressing*	*Cost \$*	*Profit*
Basic	..	..	..	..	..
Basic and potash . .	470	188	1,740 lb. M/P	18	170
Basic, potash and phosphoric acid	265	106	1,740 lb. M/P and 3,480 lb. super.	36	70

The figures for profit are obviously subject to the same experimental error as the figures for yield in Table 1.

It may be noted that the above only takes into account the 'count' bunches. The object of any scheme of manuring should be to produce the highest possible proportion of nine-hand bunches, and the curve plotted in Fig. 1 shows the effect of the potash in increasing the proportion of them. It is based on the yields of the last two years only.

Discussion.—The stools were in a poor condition when the experiment started, and it was decided to give a basic dressing of about 20 tons of pen manure per acre, as it was thought that without this, growth would be unhealthy, and complications would be introduced from the ravages of the *Tomarus* beetle (cf. *Tropical Agriculture*, 1935, **12.** 327). The general improvement in the health of the stools was marked, and the

plots have maintained a healthy normal growth throughout. It was noticed that a rather large proportion of the stems failed to stand up to the weight of the bunches. This is apparently a well-known feature of Cavendish bananas under heavy manurial treatment. No differences

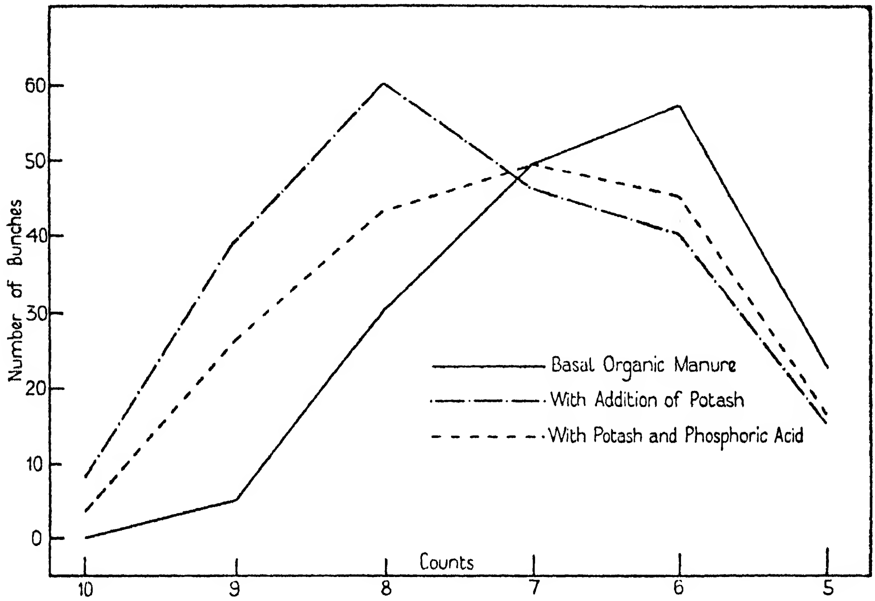

FIG. 1.

were observed between the plots in the first two years, presumably owing to the initial dressing of pen manure, but latterly the effect of potash has been most marked, and has certainly proved profitable. The action of phosphoric acid is not so marked, but it appears to depress the yield. A similar result has been observed in the manuring of sugar-cane, in the neighbourhood, where the use of phosphoric acid on soils of intermediate lime-status leads to a depression in the yield.

At the suggestion of a colleague, the precaution was taken of scratching the number of the bunch on the stem with a sharp style, as soon as possible after it appeared, and recording it forthwith. This enabled track to be kept of bunches that were stolen, and it also reduced the possibility of the incorrect allocation of bunches from the plots.

Conclusions.—It is clear that in these conditions the use of potash has brought about an increase in yield, which has been most profitable. The figures given in Table 3 refer only to 'count' bunches, but the larger number of small bunches, which can be sold locally, obtained from the plots receiving potash, will increase this figure.

The use of phosphoric acid is not recommended. It cannot be said definitely that its use has actually depressed the yield, but it certainly has not increased it, and the extra expense is not justified.

(*Received July 4, 1936*)

THE COMPOSITION OF GRASS LAID UP FOR WINTER KEEP

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Introduction.—The laying up of grass for winter keep, i.e. the enclosure of pasture fields in July or August, with a view to obtaining a substantial growth for the maintenance of outlying stock during winter, is not as yet common practice. In view of the present tendency to reduce labour charges, and the great decline in the acreage of arable land, which has caused, *inter alia*, a reduction in the amount of straw available for feeding, it seems probable that this means of conserving grass for winter keep may find an established place in the farming routine of counties enjoying moderate climatic conditions. In Northumberland the laying up of winter grass appears to be carried out in haphazard fashion; in many cases only sheep are excluded during late summer, the pasture being lightly stocked with cattle. The primary object appears to be the provision of clean land and a good 'lie' for ewes from October to January. Nevertheless, as hand-feeding is not usually resorted to until late winter, it is obvious that the quality of the grass is a very important consideration.

The term 'winter grass', as used here, refers to grass which has been grown during the previous autumn, although such grass may include some growth made during the winter months. The amount of such winter-grown grass present may be sufficiently large in the southern counties to be of practical importance, but can seldom be anything but negligible in NE. England. The few investigators who have so far interested themselves in this subject have dealt almost exclusively with winter-grown grass. In discussing methods of management and manuring calculated to produce a supply of winter grass, Stewart [1] recommends that the herbage be uniformly grazed down or mown so that by the beginning of October there is a level green sward an inch or two long. An all-round mixture of manures should then be applied, and all stock kept off until it is wanted for ewes and lambs in January. It is obvious that under such management conditions, even in the south of England, a large part of the grass available in January must have been winter grown. Recent work carried out by Woodman and Oosthuizen at Cambridge [2] is also largely concerned with winter-grown material, the yield, composition, and digestibility having been determined in pasture grass produced by unrestricted growth over the following periods: (1) end July 1932 to Dec. 1932; (2) end Aug. 1932 to Jan. 1933; (3) end Sept. 1932 to Feb. 1933; (4) end Oct. 1931 to March 1932. Although the grass produced during the last two periods was of relatively high feeding-value, Woodman admits that the yields were too low to have any significance in farming practice, and states that it would be necessary to discontinue grazing at the end of July in order to produce sufficient herbage for use during the winter. The

grass grown during the first of the above periods is comparable in certain respects with the material used in the work to be described, but Woodman does not appear to have ascertained the variation in quality which may be expected to occur during the winter.

The object of the following investigation was to determine the effect of weather conditions, and of the selective grazing of stock, on grass that was grown during late summer and autumn for providing winter keep, that was practically mature in October, and that at no period contained any considerable proportion of winter-grown herbage.

Experimental

For this investigation the authors were able to secure the use of two 3-acre plots on Roundabouts, Cockle Park. These plots, amongst others, had been used between 1929 and 1933 for an investigation into the 'intensive system' of grassland management; the treatment, manurial and otherwise, which the plots received during this period has been described elsewhere [3]. The soil, which is typical of large areas of Northumberland, is a clay loam derived from the worst type of Boulder Clay and has the following analysis:

	Per cent. of air-dry sample		*Per cent. of air-dry sample*
Coarse sand	15·20	P_2O_5, HCl-soluble	0·095
Fine sand	32·80	K_2O, HCl-soluble	0·177
Silt	12·28	P_2O_5, available	0·012
Clay	24·47	K_2O, available	0·012
Moisture	2·08		
Carbonates	nil	pH	6·34
Loss by solution	1·40		
Difference	11·77		
	100·00		

It may be noted that four years of intensive treatment had caused marked changes in the character of the sward. A botanical examination of the plots made on Nov. 26, 1934, early in the winter period, showed that in both plots the predominant herbage-component was Yorkshire Fog, this grass covering approximately 70 per cent. of the ground. Only two other species, viz. cocksfoot and creeping buttercup, made any substantial contribution, although occasional plants of perennial rye-grass, crested dogstail, Aira spp., Agrostis spp., and narrow-leaved plantain, together with such weeds as dandelion, sheeps sorrel, and acrid buttercup were noted. Wild white clover, one of the most important herbage components on this land prior to the application of intensive treatment, occupied only 5 per cent. of the ground. The contrast between the 'intensive' herbage of the experimental plots and that of adjacent land which has received only basic slag at the usual rates for many years, and contains a preponderance of wild white clover and perennial rye-grass, was most striking. That this marked botanical difference has very little effect on the relative nutritive values of the two swards has been shown by Thomas and Elliott [4].

Both plots were grazed with blue-grey bullocks and sheep during the summer, the management being such that there was very little grass on either by Aug. 4. On this date all stock were taken off, the droppings were spread with a chain harrow, and the plots laid up. On Oct. 27, one plot was stocked, and thereafter grazed at the discretion of the farm steward, who had been requested so to manage the grass that some 'keep' should be available throughout the winter, and that adequate analytical samples should be always available.

Prior to the experiment proper, samples were taken at monthly intervals throughout the summer of 1934, with a view to ascertaining the quality of spring and summer grass yielded by the plots; a standard was thus secured with which it might be possible to compare samples taken during the following winter, and which would determine the validity of comparisons made with winter grass obtained from other areas. In taking summer samples, the two experimental plots were treated as one, 5 cutting areas, each of 4 sq. yds., were located at random, cleared with heavy garden shears on April 4, 1934, and fenced with netted hurdles, which provided maximum access of light but were strong enough to exclude all classes of stock. The first samples were taken on May 2, 1934, and on the same day the fencing was transferred to five further areas which had been randomized and cleared. The samples in all cases constituted the total yield of the cutting areas and were conveyed to the laboratory in suitable bags. This procedure was continued throughout the summer, new areas being cleared and cut at regular intervals of 28 days. Six cuts in all were obtained.

On Oct. 17 the first winter samples were cut from 5 areas, each of 4 sq. yds. taken at random on both of the experimental plots. Further samples were obtained at 28-day intervals throughout the winter, the last cutting date being April 3, 1935. For reasons already indicated, the necessity for fencing did not arise during the winter period, samples being taken immediately after the randomization of the cutting areas.

The samples were dried in an air-oven at 65–70° C., and ground in a power-mill over a $\frac{1}{32}$ in. screen. Crude and true protein, ether extract, fibre, ash and ash-constituents were determined by the usual analytical methods. The method of Wedemeyer was used in determining the digestion-coefficients of the crude protein. Two-gram samples for determining moisture were weighed simultaneously with all portions required for other determinations, the moisture-content being calculated on a single weighing after an arbitrary drying-period of 24 hrs. in an electric oven at 100° C. Woodman's formula [5], which assumes a normal silica-content of 1·72 per cent. for clean grass, was used in making the necessary corrections for soil contamination.

Meteorological Data

Rainfall, sunshine, and temperature data relative to the 28-day cutting periods, together with the mean rainfall and sunshine figures for corresponding periods over the years 1924–33 are embodied in Table 1.

TABLE 1. *Meteorological Data for Period of Experiment: Cockle Park Weather Station*

Period	Rainfall (inches)	Average rainfall for 10 yrs. 1924–33 (inches)	Sunshine (hours)	Average sunshine for 10 yrs. 1924–33 (hours)	Temperature: Mean grass min. (°F.)	Temperature: Mean screen max. (°F.)	Temperature: Mean screen min. (°F.)
April 4–May 1, 1934	5·54	1·79	111·6	125·5	36·6	50·3	36·4
May 2–May 29	1·15	1·98	162·2	133·0	37·8	57·8	40·4
May 30–June 26	1·69	2·32	154·6	176·3	45·2	62·5	45·9
June 27–July 24	2·78	2·43	198·5	152·4	49·0	69·6	51·2
July 25–Aug. 21	4·04	3·35	138·9	137·8	44·1	66·0	49·5
Aug. 22–Sept. 18	1·13	1·88	159·3	138·5	43·4	64·2	43·0
Sept. 19–Oct. 16	1·79	2·56	85·6	105·0	41·0	58·2	43·9
Oct. 17–Nov. 13	5·59	2·45	78·9	95·4	35·1	47·5	37·3
Nov. 14–Dec. 11	2·92	2·60	17·7	49·5	38·9	48·6	41·0
Dec. 12–Jan. 8, 1935	3·76	2·12	25·3	45·6	36·4	46·5	38·6
Jan. 9–Feb. 5	1·48	1·93	36·7	54·7	30·7	43·8	32·8
Feb. 6–March 5	1·88	1·69	61·0	71·8	32·1	44·9	34·4
March 6–April 2	0·79	1·68	88·4	106·7	33·9	48·9	37·1

The total rainfall from April 4 to May 1 was exceptionally high; otherwise the spring of 1934 was mainly dry and bright. Temperatures were rather low during April and May. The weather was unsettled after mid-July, and from then onwards, and throughout August and September, there were frequent showers with average sunshine, and temperatures slightly above normal.

The experimental period opened in October with pastures looking fresh, the weather during this month being mainly bright, with occasional showers of sleet and snow at the end of the month.

November was dull, damp, and foggy, and the rainfall was approximately 50 per cent. higher than the average of 37 years recorded at Cockle Park for that month. Ground frosts occurred from the 1st to 4th and 6th to 9th, inclusive.

December was characterized by an exceedingly high rainfall, little sunshine, and abnormally high temperatures. Grass looked particularly green and fresh during this month.

The weather during Jan. 1935 was mainly dry and mild, with sharp frosts between the 7th and 9th and wintry conditions during the last few days of the month. Between the 24th and 27th there was a NW. gale accompanied by a snowfall of 4 in., which lay until the 29th.

February was unsettled and stormy with high W. and NW. winds. The first and last weeks were cold, with ground frosts; during the remainder of the month temperatures were above normal. Snow fell between the 23rd and 27th.

The first five days of March were wet, but less than 0·75 in. of rain fell during the rest of the month. Winds were light and variable in direction. Ground frosts were experienced on eight days, but temperatures were generally high.

The weather during the winter of 1934–5 might be described as 'muggy'. The rainfall from Oct. to Dec. 1934 was well above the average for the previous ten years. Throughout the winter the amount of bright sunshine was lower and the temperatures higher than the averages.

Results

The composition of grass samples taken from the two plots during the winter of 1934–5 is shown in Table 2, each figure being the mean of analyses made on five replicate samples.

TABLE 2. *Composition of Grass Samples, 1934–5. Percentage of Soil-free Dry Matter*

PLOT A (ungrazed)

	1934			1935				
	Oct. 17	*Nov. 14*	*Dec. 12*	*Jan. 9*	*Feb. 6*	*March 6*	*April 3*	*Season mean*
*Crude protein.	13·94	12·35	11·29	13·59	12·66	13·75	13·80	13·05
Ether extract	3·20	3·05	2·80	2·77	2·25	3·20	2·45	2·82
N-free extractives	49·54	49·52	49·19	46·40	51·16	49·97	50·77	49·51
Crude fibre	25·52	27·57	30·51	31·33	29·22	28·40	28·23	28·68
†Ash	7·80	7·51	6·21	5·91	4·71	4·68	4·75	5·94
*Including: True protein.	11·78	10·08	8·94	11·32	10·52	11·31	12·19	10·88
†Including: Phosphoric acid (P_2O_5)	0·897	0·753	0·845	0·909	0·845	0·839	0·763	0·836
Lime (CaO)	0·814	0·618	0·826	0·858	0·612	0·562	0·602	0·699
Digestibility of crude protein (Wedemeyer)	76·20	68·04	53·69	52·65	58·16	61·22	64·70	62·01
True/crude protein ratio	0·85	0·80	0·79	0·83	0·83	0·82	0·89	0·83

PLOT B (grazed)

	Oct. 17	*Nov. 14*	*Dec. 12*	*Jan. 9*	*Feb. 6*	*March 6*	*April 3*	*Season mean*
*Crude protein.	13·32	14·31	13·23	12·91	14·08	13·83	15·06	13·82
Ether extract	3·22	3·03	2·87	2·90	2·04	2·05	1·84	2·57
N-free extractives	50·45	48·44	47·22	47·92	50·70	50·77	52·00	49·64
Crude fibre	25·67	26·90	30·22	30·26	27·61	28·18	26·14	27·85
†Ash	7·34	7·32	6·46	6·01	5·57	5·17	4·96	6·12
*Including: True protein.	11·76	11·83	10·23	11·32	12·40	12·02	13·39	11·85
†Including: Phosphoric acid (P_2O_5)	0·848	0·883	0·813	0·914	0·928	0·809	0·831	0·861
Lime (CaO)	0·912	0·832	0·796	0·678	0·480	0·536	0·766	0·714
Digestibility of crude protein (Wedemeyer)	69·52	61·77	57·85	54·34	61·67	58·24	63·10	60·93
True/crude protein ratio	0·88	0·83	0·77	0·88	0·88	0·87	0·89	0·86

In the absence of replicated treatments it was impossible to determine the variance due to soil heterogeneity in a direction at right angles to the main axes of the plots. As the experimental site was chosen with care, and as there was no reason to suppose that such soil heterogeneity existed, the validity of the conclusions drawn from comparisons made between the two treatments is unlikely to be affected.

The observed effects of season and treatment on some of the principal constituents of the grass, and the significance of such effects, are briefly summarized below:

Crude protein.—The crude-protein figures have proved to be less satisfactory than those for any other single constituent with the possible exception of phosphoric acid, in that replicate samples showed consider-

able variation. From an inspection of the means it would appear that, on the ungrazed plot, there was a decline between Oct. 17 and Dec. 12, followed by a marked increment in January. Thereafter, the crude-protein content remained substantially constant until the end of the period. On the grazed plot the protein followed a somewhat similar course, but sharp increases occurred between the first and second and the sixth and seventh cuttings. The means for the whole winter period showed a difference of 0·77 per cent. in favour of the grazed plot. The digestion-coefficients were very consistent on both plots, falling to a minimum in January and rising thereafter.

True protein.—During the first half of the winter there was a fairly well-marked fall in the percentage of true protein present in the grass from both plots, a minimum being reached in December. This decline was accentuated in the ungrazed herbage.

In both cases the ratio of true to crude protein fell during early winter and reached a minimum in December, rose sharply during January, and afterwards showed little variation.

Crude fibre and ether extract.—The percentage of crude fibre in the herbage of both plots rose markedly to a maximum in December. On the ungrazed plot there was an apparent decline from January; under grazing the fibre followed a similar course, except that a temporary increase occurred in the samples of March 6. With one exception (Oct. 17), the ungrazed plot has shown a higher fibre-content on every cutting occasion, the seasonal mean being greater than on the grazed plot to the extent of nearly one per cent.

The ether extract of the ungrazed herbage fell consistently between October and February, but rose sharply in March to fall again in April. On the other plot this constituent declined from the beginning to the end of the winter period with some regularity, although there were checks during the periods Dec. 12—Jan. 9 and Feb. 6—March 6. The difference between the seasonal means for the two treatments was 0·25 per cent.

Ash and ash-constituents.—The soil-free ash of the ungrazed grass fell consistently until Feb. 6, this decline being of undoubted significance; during the rest of the winter period it continued at a low level. From a study of the means it is obvious that the phosphoric-acid content of grass from this plot did not vary to any considerable degree during the winter. The agreement between replicates was, however, not close enough to warrant any conclusions as to the significance of the relatively small differences between means. The mean lime-content appears to show some irregularity, but no real decline occurred until after Jan. 9; from Feb. 6 onwards it must be considered to have remained constant at a lower level.

On the grazed plot there was a steady fall in the amount of soil-free ash present from Nov. 14 until April 3, the difference between the ash-contents on these two dates being very large. The mean values for phosphoric acid on this plot were similar to those obtained on the ungrazed land, and for the reasons given above, no significance can be attached to the small differences found. There was a regular fall in

lime-content from the beginning of the winter until Feb. 6; the following two cuttings showed a sharp rise. The seasonal means for ash, phosphoric acid, and lime were not disparate as between the grazed and ungrazed plots, although they were slightly higher on the former.

Discussion

The results shown in Table 2 indicate that grass produced under the conditions of this experiment retained an unexpectedly high feeding-value, even after exposure to several months of wintry weather. Indeed, the mid-winter samples compare not unfavourably with month-old grass from many of the poorer Boulder Clay pastures, and are apparently superior to still younger grass from unimproved land of the type represented by Plot 6 of Tree Field and untreated areas of Paradise at Cockle Park. Thomas and Elliott [6] showed that out of twelve fortnightly samples taken from the former during the growing season of 1930, only two contained more than 9·0 per cent. of crude protein, and the phosphoric acid exceeded 0·5 per cent. on only one occasion. It would be rash to dogmatize in the absence of complete digestibility data, but large differences like those noted above would probably suffice to balance, or even outweigh, the reduced digestibility of the winter grass.

The Roundabouts Field, on which the experiment was conducted, might be described as a well-managed Boulder Clay pasture, and is undoubtedly in a high state of fertility. A good indication of the quality of the grass which it produces may be obtained from Table 3, which shows the composition of monthly samples taken during the growing-season of 1934.

TABLE 3. *Composition of Grass from Roundabouts Field, Cockle Park (1935). Percentage of Soil-free Dry Matter*

	May 2	*May 31*	*June 29*	*July 25*	*Aug. 24*	*Sept. 17*
*Crude protein	19·67	16·03	16·50	18·81	20·50	23·26
Ether extract	3·21	3·06	3·01	3·34	3·99	3·65
N-free extractives	48·69	49·70	50·98	46·08	45·85	42·61
Crude fibre	19·57	23·15	21·60	22·66	20·72	20·90
†Ash	8·86	8·06	7·91	9·11	8·94	9·58
*Including:						
True protein	16·57	13·22	14·96	14·80	16·74	19·19
†Including:						
Phosphoric acid (P_2O_5)	1·058	1·036	0·991	1·118	1·098	1·246
Lime (CaO)	1·298	1·419	1·534	1·598	1·431	1·368
Digestibility of crude protein (Wedemeyer)	74·68	79·39	66·38	75·47	74·72	78·58
True/crude protein ratio	0·84	0·83	0·91	0·80	0·82	0·82

In comparing winter and summer grass, it should be borne in mind that the former was approximately 2½ months old when the winter period opened on Oct. 17. As already indicated, the crude-protein content of the 'laid-up' grass remained at a useful level throughout the

winter; it was, nevertheless, substantially less than in summer grass of the age at which it is normally grazed. The digestibility of this constituent was also lower in the winter samples, although it did not fall to the extent anticipated, and was never less than 50 per cent.

The comparatively high mineral efficiency of the winter grass and the manner in which this efficiency has been maintained, at least in so far as the phosphoric acid is concerned, is possibly of greater interest than any other information which has emerged from this investigation. Throughout the winter the phosphoric-acid content never fell below 0·8 per cent. on the grazed plot, and was less than this figure on only two occasions where the grass was unstocked. Although the lime-content was satisfactory during the early part of the winter, later on it declined considerably. This decline started at an earlier date and was more marked on the grazed plot.

Although the mineral efficiency of the winter grass, as judged by its contents of lime and phosphoric acid, is certainly less than that of month-old summer grass, it would appear to be more than adequate for the needs of the classes of stock commonly out-wintered. The consistent decline in the ash-content during the winter suggests that other mineral constituents are more seriously depleted than the lime and phosphoric acid.

The crude-fibre content of the winter grass from both plots was markedly higher than that normally associated with summer growth, and the digestibility of this constituent had probably depreciated to a serious extent. Woodman and Oosthuizen [2] have shown that the digestion-coefficient of the crude fibre of grass laid up at the end of July and sampled early in December was 59·7 per cent., as against 83·7 per cent. in young spring grass from the same field.

Nevertheless, winter grass compares very favourably indeed with hay grown on similar land at Cockle Park which has been well done for many years. For purposes of comparison, Plot 12, Palace Leas, which has received an annual dressing of 300 lb. basic slag and 100 lb. muriate of potash per acre, and which has been shown to be one of the best plots on that field, may be used. The crude-protein content of the 1932 hay crop from this plot proved to be 9·53 per cent., and to have a digestion-coefficient of 74·91. The digestible protein therefore amounted to 7·13 per cent., as against seasonal means of 8·42 and 8·09 per cent. for winter grass from the grazed and ungrazed plots, respectively. The crude fibre was 31·12 per cent., as against 27·85 and 28·68 per cent. respectively. The lime-content of the hay (0·79 per cent.) was slightly higher than either of the seasonal means for the winter grass, but it may be noted that most of the cuts taken before Jan. 9, 1935, were actually superior to the hay in this respect. The hay appears to be definitely inferior to winter grass in respect of phosphoric acid, showing only 0·69 per cent. as against 0·86 and 0·84 per cent., respectively. Unfortunately no reliable data as to the weights of dry matter present on the experimental plots at the beginning of winter are available, but they were estimated to have been not less than 3,500 lb. per acre. In any circumstances a yield of 2,500 to 3,000 lb. might be expected from similar

Boulder Clay pastures which have been managed rather less efficiently. That substantial yields may be obtained from land laid up in late summer is indicated by results collected during recent years on experimental grassland plots at Cockle Park. In the season of 1930 the mean dry-matter yield from five plots on Tree Field, between July 23 and the end of the growing-period, was 2,234 lb. per acre, and constituted 56 per cent. of a total yield of 4,001 lb. secured from cuttings taken at intervals of fourteen days throughout the season (May 12–Oct. 13). Mercer [7] has stated that, on permanent grassland at Reaseheath, the yield for monthly cuts taken after June 20 amounted to approximately 60 per cent. of the total.

The cause of the rather marked seasonal variation in fibre-content, which has been shown to occur, is probably less obvious than it might seem. Woodman and Oosthuizen [2] have shown that the re-elaboration of material which sets in with the incidence of hard weather, and which is accompanied by lignification of the cellulose, raises the fibre-content to only a slight degree, although it has markedly depressing effects on digestibility. It is unlikely that the absolute amount of fibre present varies to the extent implied by the figures; the substantial increase in the fibre-content of the dry matter which occurs between October and January is probably, in part, a reflection of losses sustained by other constituents owing to the slowing down of photosynthesis. Despite the fact that the early winter of 1934–5 was not unduly severe, the climatic conditions at Cockle Park are such that this increase in fibre-content can hardly be ascribed entirely to maturation.

The decline in crude-protein content which appears to occur on both plots during the first months of the winter is probably due to evacuation from the foliage. The increasing proportion of non-protein nitrogen shown to be present indicates that hydrolysis is playing the major part in protein metabolism at this time of the year. Thomas [8], in a study of the nitrogen metabolism of apple trees, showed that, in autumn, there is migration of nitrogen from the leaves to the branches. At first sight the fall in true protein, and in the ratio of true to crude protein, appears somewhat surprising, but it may be explained as resulting from two causes. The degradation of protein prior to translocation of nitrogen from the leaves must be considered as responsible in some measure for the accumulation of non-protein nitrogen. The second factor concerned is low temperature. Harvey [9], after investigating the effect of frost and low temperature on various succulent plants, concluded that, although changes in the carbohydrate values are slight, the amino-acid content increases. In an investigation of the winter hardiness of wheat, Newton [10] found that all the varieties used in his experiments increased in amino-nitrogen and water-soluble nitrogen during hardening. It is possible to explain the very marked fall in the digestibility of the crude protein between October and January on the grounds that hydrolysis has been confined to the non-nuclear proteins. It follows that the ratio of so-called nucleo-proteins to total crude protein would rise. As the nucleo-proteins on digestion with pepsin are very incompletely hydrolysed, leaving an insoluble residue of protein combined with

nucleic acid, it is obvious that the digestion-coefficient of the crude protein, as determined by the method of Wedemeyer, would fall. The renewal of protein synthesis and growth early in the New Year accounts for the rise in digestibility which was first observed in the cutting of Feb. 6.

Reference has already been made to the consistent decline in the ash-content throughout the winter. As the phosphoric-acid content remains remarkably constant, and as the lime suffers serious depreciation only after January, it appears that the loss has fallen largely on ash-constituents not determined in the course of this work. The authors are not prepared to account for such loss, but suggest that one or both of two factors may be responsible: viz. (*a*) leaching, following severe frost damage or injury due to treading, (*b*) translocation. Woodman and Oosthuizen [2] have stated that the lime-content of grass is depressed by exposure to frost, and it is possible on these grounds to explain the marked decline in lime-content which occurred on both plots in early spring. It is noteworthy that the percentage of lime present fell sharply in the cutting of Nov. 14, which followed immediately after a series of ground frosts.

Much emphasis is laid on the selective action of stock in grazing, and it might reasonably be anticipated that any such selectivity as may be exercised would be reflected in the chemical composition of the sward, and that there would be an appreciable fall in the percentage of such constituents as crude protein, phosphoric acid, and lime. From a comparison of the relevant data in Table 2, it appears that the present experiment has afforded no evidence of selective grazing. The grazed plot actually shows somewhat higher seasonal means for protein, phosphoric acid, and lime, and a lower mean for crude fibre.

Summary

The effects of grazing, seasonal, and other factors on the composition of grass laid up for winter keep have been studied.

The crude-protein content of the grass declined between October and December on grazed and ungrazed plots alike, but rose again in late winter with the resumption of growth. The digestion-coefficients fell with great consistency to a minimum in January and rose thereafter, the decline being accentuated on the ungrazed herbage. A similar fall in early winter was shown by the ratios of true to crude protein. An attempt has been made to give some physiological explanation for the changes which have occurred in the nitrogen constituents of the dry matter.

Seasonal changes in the crude-fibre content of grass from both experimental plots were essentially similar, maxima being reached in January.

Ether extract follows the same general trend under both treatments, and the amounts declined with some regularity throughout the winter.

On both plots the ash-content showed marked seasonal variation, falling steadily from the beginning to the end of the experimental period. This loss of mineral matter was not due to any decline in the phosphoric-acid content. It is suggested that losses sustained by the lime and by

ash-constituents not determined in the course of this work can be attributed to translocation and leaching, the latter possibly following on injury due to frost or other causes.

The nutritive value of winter grass, as judged by its chemical composition, is inferior to that of summer grass from the same pasture and of an age at which it is normally grazed. Nevertheless, the mineral efficiency of the winter grass was comparatively high, and it compared favourably in this and other respects with month-old summer grass from inferior Boulder Clay pastures, and with hay from one of the best meadow plots at Cockle Park.

The present experiment has failed to provide evidence of selective grazing by out-wintered stock.

It is suggested that the practice of laying up grass for winter keep affords a useful means of conservation which might be more widely employed in districts enjoying moderate conditions of climate.

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EXPERIMENTS ON THE GROWING OF CHICORY (FOR DRYING)

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THE erection of a factory for drying chicory at Needingworth, near St. Ives, Huntingdonshire, afforded an opportunity for farmers and smallholders in the district to introduce another cash crop, grown on contract at a fixed price, into their crop rotation. In view of the interest shown in the cultivation of the crop, some experiments were carried out in the district in the seasons 1932, 1933, and 1934 with a view to ascertaining if the crop had any special manurial requirements, and in what respects, if any, its treatment should differ from that adopted for a crop such as sugar-beet.

The soils on which most of the crop is grown are gravelly loams and fens, owing to the difficulty of lifting such a deep-rooting crop on heavy soils. For this reason the experimental centres were situated on these two types of soil.

The condition or 'heart' of the soils at the experimental centres, as judged by past history and soil analysis, was reasonably good and fairly representative of much of the land on which chicory is usually grown in the district. Striking responses to manurial treatment could not therefore be expected, nor were they obtained in practice, though this fact must not be interpreted as indicating the likelihood of a similar small response on soils in a low state of fertility or in a different district.

The results obtained are described below under the three headings: Manuring, Spacing, and Effects of Soil Acidity.

In all cases the experimental plots were arranged either in Latin squares or randomized blocks, each treatment being replicated at least four times at each centre. At most centres individual plots were from 1/80th to 1/100th acre. In the spacing trials, the three singling-distance sub-plots were randomized over each main row-width plot, and hence were only one-third of this area.

Experiments on the Manuring of Chicory

Four centres were situated on light soils, three being on gravelly loams and one (Centre 3) on light sand. Centres 1 and 4 were on fields which had been well cultivated and liberally manured for some years, and their yields of chicory may be taken as a fair example of what can be grown on such land when properly cultivated.

Centre 2 was on land which was not in such good heart as the other two gravel-loam centres, neither was the land as clean, for despite a bare fallow in the previous year, the 1933 chicory crop suffered very

considerably from weed-competition. The harmful effects of this weed-competition were accentuated by very dry weather immediately after seeding, and indeed right up to singling-time, which considerably delayed that operation. The weed-growth during this period also rendered singling much more difficult and increased the loss of plant at this stage, as will be seen from the fact that, with rows 16 in. apart, the average plant-population was only 25,000 per acre. Despite the low average yield at this centre it will be seen from Tables 1 and 2 that the response to

TABLE 1. *Effect of Nitrogen, Phosphorus, and Potassium Yield of Chicory (tons per acre)*

	Centre 1 1934	*Centre 2 1933*	*Centre 3 1933*	*Centre 4 1932*	*Centre 5 1933*	*Centre 6 1932*
NPK	13·71	7·2	6·6	10·45	18·25	8·70
NP	13·96	6·4	6·25	10·45	18·15	9·40
NK	14·59	6·65	6·2	11·02	18·35	8·71
PK	13·50	7·0	6·1	10·30	18·0	9·0
Nil	13·67	6·8	5·55	9·68	17·7	9·30
Standard error	0·51	0·37	0·7	0·84	0·67	0·39

N.B.—(1) N = Nitro-chalk at 3 cwt. per acre in two equal doses.
P = Superphosphate at 3 cwt. per acre.
K = Muriate of potash at 1½ cwt. per acre.
(2) The 1932 figures are actual factory-washed weights; the other figures are yields of roots knocked as clean as possible in the field but not washed.
(3) No dung was applied for the chicory crop at these six centres.
(4) At all centres the effect of treatment was insignificant when tested by Fisher's 'z' test.

artificial fertilizers was relatively small, and that the response to 3 cwt. of nitro-chalk was no greater than the response to 1½ cwt., a fact suggesting that the effect of fertilizers was here limited by the generally unsuitable soil conditions and by the irregular plant left after singling. The effect of the unsatisfactory plant and the delay in singling may be seen by comparison with the results obtained in a spacing trial on an adjacent strip of land in the same field (Centre 7, Table 3). The spacing trial, though sown on the same day, was singled earlier and more carefully than the manurial trial, and even on 18-in. rows 27,000 plants per acre were obtained on the widest (12 in.) singling, which resulted in a yield equal to the average of the manurial trial, the yield increasing very rapidly with closer spacing.

A similar low response to fertilizers, despite a low average yield, will be seen in the case of Centre 3, and here again dry soil conditions, combined with patches of twitch, and slight soil acidity (an application of lime was made for the chicory crop but not early enough in view of the dry weather), resulted in a somewhat irregular plant and a final crop yield considerably below that obtained on an adjacent spacing trial (Centre 8, Table 3), where a full plant was obtained and soil conditions were generally more favourable.

Two centres, numbers 5 and 6, were situated on black fen land, the former having the better soil of the two. A third fen-land centre had to

be abandoned owing to loss of plant due to wind-storms while the crop was in the seedling stage. The low yield at Centre 6 was again probably due, in part at any rate, to lack of care at singling. The higher yield at Centre 5 is more typical of what can be obtained on good fen soil, bearing in mind that no deduction for dirt tare was made in the weights at this centre. A point of interest at Centre 5 is that, with rows 16⅝ in. apart, the average plant-population was 48,844 per acre, and the average root-weight was maintained at the satisfactory level of 0·85 lb.

None of the fertilizer treatments gave statistically significant increases in yield of chicory. On light soils (Centres 1 to 4) the application of a complete fertilizer supplying nitrogen, phosphorus, and potash gave a small increase in yield over the unmanured plots, the average increase being 11¼ cwt. per acre. The omission of nitrogen or potash from the complete fertilizer resulted in a slight reduction in yield—approximately 5 cwt. per acre in each case, whilst the omission of superphosphate caused no reduction at Centres 1 and 4, but a reduction of nearly 10 cwt. per acre at Centres 2 and 3, which were known to have been less liberally treated in this respect in recent years.

It does not appear likely, therefore, that on soils in a normal state of fertility, the chicory crop has any very pronounced requirement for one element of plant-food more than for any other; neither does it respond very markedly to heavy applications of complete artificial fertilizers in such circumstances.

The results obtained in experiments dealing with the quantity and time of application of the nitrogenous part of the fertilizer mixture, carried out on the same four light-land farms, are shown in Table 2.

TABLE 2. *Yield of Chicory (tons per acre)*

Nitrogenous manuring	*Centre 1 1934*	*Centre 2 1933*	*Centre 3 1933*	*Centre 4 1932*
3 cwt. per acre Nitro-chalk before seeding	14·13	7·4	6·5	11·11
1½ ,, ,, ,, ,, ,, ,, } 1½ ,, ,, ,, ,, at singling }	13·71	7·2	6·6	10·91
1½ ,, ,, ,, ,, before seeding	14·22	7·4	6·6	11·08
No Nitro-chalk	13·50	7·0	6·1	10·39
Standard error	0·51	0·37	0·7	0·15

N.B.—The effect of treatment was only significant by Fisher's '*z*' test at Centre 4, where all three nitrogenous treatments gave significantly higher yields than plots receiving no nitrogenous fertilizer.

It will be seen that no yield-increase was obtained beyond that for the first 1½ cwt. per acre of nitro-chalk, no matter whether the additional application was made prior to seeding or at singling time.

As in the case of sugar-beet, chicory is reputed to respond well on the Continent to heavy dressings of artificial fertilizers, but it appears that, in the present state of our knowledge of the cultivation of the crop in this country, other factors, such as soil tilth, plant-population, and weather conditions may frequently be of greater primary importance. It should be borne in mind, however, that in two of the seasons under review

the dry weather conditions during the summer months tended to reduce the availability of artificial fertilizers applied direct to the crop, especially those applied as late top dressings.

Experiments on the Spacing of Chicory

Centres 7 and 9 were on gravel-loam soils and Centre 8 on a light sandy soil. The desired row-widths were obtained in all cases, but at singling time the workers were instructed to single the plants as closely as possible to the desired distances, only the first few plants in each case being accurately measured. Hence the final crop was rarely spaced with

TABLE 3. *Experiments on the Spacing of Chicory*

Row-width (in inches)	Singling-distance (in inches)	Actual no. of plants per acre in thousands			Yield in tons per acre			Yield referred to 18 × 12 in. work as 100			Average weight per root (in lb.)		
		Centre 7	Centre 8	Centre 9	Centre 7	Centre 8	Centre 9	Centre 7	Centre 8	Centre 9	Centre 7	Centre 8	Centre 9
18	12	27	31	33	6·7	9·4	8·9	100	100	100	0·6	0·7	0·7
18	9	28	36	38	6·9	9·9	9·5	102	106	107	0·6	0·6	0·6
18	6	34	41	42	7·4	9·8	8·7	111	104	99	0·5	0·6	0·4
15	12	30	43	43	10·0	9·8	10·4	148	105	117	0·7	0·5	0·6
15	9	36	42	48	10·5	8·7	10·9	156	93	123	0·7	0·5	0·6
15	6	40	58	51	9·5	10·5	11·0	141	112	124	0·5	0·4	0·5
12	12	41	46	57	10·0	9·2	11·3	148	98	127	0·6	0·5	0·5
12	9	47	54	54	12·2	10·3	11·5	182	110	130	0·6	0·5	0·5
12	6	62	63	61	14·4	11·4	12·1	214	121	136	0·5	0·4	0·5

SUMMARY OF SPACING RESULTS

(*a*) Relative yields referred to 18-in. rows as 100

		Centre 7	*Centre 8*	*Centre 9*
On 18-in. rows—mean of all singling distances	=	100	100	100
,, 15-in. ,, ,, ,,	=	142	100	119
,, 12-in. ,, ,, ,,	=	174	106	129
Standard error	=	2·5	3·2	2·1

(*b*) Relative yields referred to 12-in. singling as 100

		Centre 7	*Centre 8*	*Centre 9*
With 12-in. singling—mean of all row-widths	=	100	100	100
,, 9-in. ,, ,, ,,	=	111	102	104
,, 6-in. ,, ,, ,,	=	117	112	104
Standard error	=	6·7	4·4	1·9

Despite considerably higher yields obtained in conjunction with close singling, the effect of singling-distance was not statistically significant, nor was the interaction between singling-distance and row-width. Narrow rows gave significantly higher yields than wide rows at Centres 7 and 9, but not at Centre 8.

any great precision, but represented rather the plant-distribution which would be obtained in farming practice when attempting to achieve the different spacings. The 6-in. spacing, as might be expected, was most difficult to obtain, and it is noteworthy that the accuracy at this spacing was no greater on rows 18 in. apart than on rows only 12 in. apart. Nine-inch spacing was achieved with fair accuracy on all row-widths at Centres 8 and 9, but not so well at Centre 7. Twelve-inch spacing was obtained on the 18-in. rows, but the plants were left rather too close at all centres on the narrower row-spacings.

The results indicate the importance of close spacing if high yields are to be obtained, especially as regards row-width. Close singling proved even more important at all centres on narrow (12 in.) rows than on wide (18 in.) rows.

The whole question of the effect of plant-population on crop yield is surrounded by many difficulties, as in the sugar-beet crop, but the results obtained in these experiments on chicory bear out Continental experience as to the importance of narrow spacing, and it is suggested that where practical considerations permit, the row-width for chicory should be not more than 15 in. and the singling-distance not more than 9 in. This is closer spacing than is usually adopted for sugar-beet, and necessitates careful work with implements and a considerable amount of hand labour, but where this is available, as on smallholdings, the increase in yield can reasonably be expected to compensate for the additional time and labour.

Effect of Soil Acidity on Growth of Chicory

Observations such as those made at Centre 3 demonstrated the reduction in plant-population, vigour of growth, and final yield of chicory consequent on soil acidity.

In a long-term liming experiment, established in December 1931 by one of the writers in co-operation with Mr. J. W. Dallas, Agricultural Organizer for Bedfordshire, chicory was sown in the season 1933. The results obtained showed statistically significant increases in the yield of chicory on the limed plots. Details of the soil analysis and yields of chicory are shown in Table 4.

TABLE 4. *Effect of Soil Acidity on Yield of Chicory*

Soil: loamy sand (clay 10 per cent., sand 67 per cent.).
Exchangeable calcium (per cent. CaO) = 0·07 per cent.
Hutchinson & McLennan lime-requirement: 0·19 per cent. $CaCO_3$ (pH value = 5·9).
Yield of chicory on limed plots: 10 tons 13 cwt. per acre.
" " " unlimed plots: 8 tons 13 cwt. per acre.
Standard error: 11 cwt. per acre.

General experience seems to indicate that in its susceptibility to the harmful effects of soil acidity, chicory is very similar to sugar-beet.

Conclusions

1. Experiments conducted during the years 1932, 1933, and 1934 failed to show any large response by the chicory crop to applications of complete artificial fertilizers, and no special requirement by the crop for any one particular element of plant-food more than any other on soils in a normal state of fertility. No evidence was obtained to support the practice of withholding part of the nitrogenous dressing till singling time, and it is suggested that a moderate dressing of a complete fertilizer, such as that commonly used for the sugar-beet crop growing under similar conditions, is suitable for the chicory crop, the whole application being worked into the soil prior to seeding.

2. Spacing trials showed that considerable increases in yields were obtained where close spacing was adopted. Although these trials are

open to the criticism that the spacings attempted were rarely obtained in practice and the data therefore represent the results of a somewhat irregular plant-population, they do indicate the importance of close spacing. The effect of row-spacing was particularly pronounced, and whilst realizing the practical difficulties sometimes involved, it is suggested that the spacing adopted for chicory should certainly be closer than for the sugar-beet crop—a fact which itself suggests the suitability of the crop for smallholdings rather than extensive farming conditions.

3. Soil acidity has been shown to cause serious reduction in the yield of the chicory crop.

4. On gravel-loam soils in normal condition, average yields of 10 tons per acre of chicory roots can be obtained under ordinary farming conditions. On good fen soils yields should reach 15 tons per acre.

5. Experience gained in the course of these trials has shown the great importance of careful preparation of a good seed-bed and early and careful singling of the crop.

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